PB82-249103

The Application of Decision Analysis to Toxic Substances: Proposed Methodology and Two Case Studies

Decision Focus, Inc.
Palo Alto, CA

Prepared for

Environmental Protection Agency
Washington, DC

Dec 81

U.S. Department of Commerce
National Technical Information Service
NTIS

PB82-249103

EPA Report Number: 560/4-82-003
June 1982

THE APPLICATION OF DECISION ANALYSIS TO TOXIC SUBSTANCES:
Proposed Methodology and Two Case Studies

by:

Gregory L. Campbell
David Cohan
D. Warner North

EPA Contract 68-01-6054

Project Officer:
Michael H. Shapiro
Economics and Technology Division
Office of Toxic Substances
Washington, D.C. 20460

OFFICE OF PESTICIDES AND TOXIC SUBSTANCES
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

1084-0

50272-101

REPORT DOCUMENTATION PAGE

1. Report No. EPA 560/4-82-003

2.

3. Recipient's Accession No. PB82 249103

4. Title and Subtitle
THE APPLICATION OF DECISION ANALYSIS TO TOXIC SUBSTANCES:
Proposed Methodology and Two Case Studies

5. Report Date December 1981

6.

7. Author(s) Gregory L. Campbell, David Cohan, D. Warner North

8. Performing Organization Rept. No. DFI Project 1084-0

9. Performing Organization Name and Address
Decision Focus Incorporated
5 Palo Alto Square, Suite 410
Palo Alto, CA 94304

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) 68-01-6054
(G)

12. Sponsoring Organization Name and Address
Economics and Technology Division
Office of Toxic Substances
Environmental Protection Agency
Washington, D.C. 20460

13. Type of Report & Period Covered Final Report, 1980-1981

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This research report investigates the use of decision analysis as an aid to decisions on toxic substance regulation. Part I of this report includes a literature survey on decision analysis and related methods for quantitative analysis and an exposition of the proposed methodology. Parts II and III illustrate the decision analysis approach on two chemicals, perchloroethylene (PCE) and di-ethylhexyl phthalate (DEHP). The PCE case study illustrates how uncertainties in the potential chronic health effects of a chemical may be quantitatively described in a way that makes use of bioassay data and scientific judgment on the extrapolation of the dose response relationship from animals to humans. The PCE analysis includes a comparison of control options to workers, service users, and the general public, showing the potential impact on health for each group and comparing expected health benefits to control costs. The value of better information to resolve health effect uncertainties is computed and compared to the cost of large-scale animal tests. The DEHP analysis illustrates an economic analysis of regulatory costs based on interproduct substitution among DEHP and competing plasticizers.

17. Document Analysis a. Descriptors

Cost-Benefit Analysis, Decision Analysis, Risk Analysis, Risk Assessment, Bayesian Decision Theory, Perchloroethylene, Tetrachloroethylene, Di-ethylhexyl Phthalate

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement:
Unrestricted availability through NTIS or performing organization at cost of reproduction.

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 465

22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

This report was prepared under contract to an agency of the United States Government. Neither the United States Government nor any of its employees, contractors, subcontractors, or their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product, or process disclosed in this report, or represents that its use by such third party would not infringe on privately owned rights.

Publication of the data in this document does not signify that the contents necessarily reflect the joint or separate views and policies of each sponsoring agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Preparation of this document was completed prior to January 22, 1982, the effective date of the EPA Administrator's Order 2200 and, consequently, the document did not necessarily undergo the peer review procedures described therein. The document received peer review according to procedures in place prior to that date and received complete administrative review.

CONTENTS

Part I

THE APPLICATION OF DECISION ANALYSIS TO TOXIC SUBSTANCES

Section Page

1 INTRODUCTION AND SUMMARY 1-1

2 LITERATURE REVIEW 2-1

3 DECISION ANALYSIS METHODOLOGY FOR UNREASONABLE RISK DETERMINATION 3-1

4 REFERENCES 4-1

Part II

PERCHLOROETHYLENE: A CASE STUDY OF THE APPLICATION OF DECISION ANALYSIS TO THE DETERMINATION OF THE RISK POSED BY A TOXIC CHEMICAL

Section Page

1 INTRODUCTION AND SUMMARY 1-1

2 THE DRY CLEANING INDUSTRY 2-1

3 PCE EXPOSURE CALCULATIONS 3-1

4 CONTROL OPTIONS 4-1

5 HEALTH EFFECTS OF PERCHLOROETHYLENE 5-1

6 MODEL FOR DOSE RESPONSE RELATIONSHIP FOR PCE 6-1

7 ANALYSIS OF CONTROL OPTIONS 7-1

8 VALUE OF FURTHER INFORMATION 8-1

9 INSIGHTS FROM THE PERCHLOROETHYLENE CASE STUDY 9-1

10 REFERENCES 10-1

APPENDIX A: CALCULATING AN ANNUAL CAPITAL CHARGE FOR AN INVESTMENT A-1

APPENDIX B: DETAILED CALCULATIONS OF CONTROL COSTS AND EXPOSURE REDUCTION B-1

APPENDIX C: CALCULATIONS OF PROBABILITY OF INCIDENCE AND EXPECTED CANCER CASES BY CONTROL OPTION AND DOSE RESPONSE CASE C-1

CONTENTS (continued)

Part III

DI-ETHYHEXYL PHTHALATE: A CASE STUDY OF THE APPLICATION OF DECISION ANALYSIS TO THE DETERMINATION OF RISK POSED BY A TOXIC CHEMICAL

Section **Page**

1 INTRODUCTION AND SUMMARY 1-1

2 PLASTICIZERS 2-1

3 THE PROTOTYPE PLASTICS INDUSTRY MODEL 3-1

4 RESULTS FROM USING THE PROTOTYPE MODEL 4-1

5 POTENTIAL DEVELOPMENT AND USE OF THE ECONOMIC ANALYSIS MODEL 5-1

6 REFERENCES 6-1

APPENDIX A: DATA FOR THE PROTOTYPE PLASTICS INDUSTRY MODEL A-1

APPENDIX B: RESULTS OF POLICY AND SENSITIVITY ANALYSIS CASES USING THE PROTOTYPE PLASTICS INDUSTRY MODEL B-1

ABSTRACT

Many of the provisions of the Toxic Substance Control Act (TSCA) require a finding that a chemical or mixture presents or may present an "unreasonable risk" to human health or the environment. The Act and its legislative history leave ambiguous the extent to which methods such as cost-benefit analysis, risk assessment, and decision analysis are appropriate to use in determining whether a chemical or mixture presents an "unreasonable risk."

Decision analysis provides an extension of cost-benefit methods to deal explicitly with uncertainty. This research report investigates the use of decision analysis as an aid to decisions on toxic substance regulation. Part I of this report includes a literature survey on decision analysis and related methods for quantitative analysis and an exposition of the proposed methodology. Parts II and III illustrate the decision analysis approach on two chemicals of current regulatory concern, perchloroethylene (PCE) and di-ethylhexyl phthalate (DEHP). The PCE case study illustrates how uncertainties in the potential chronic health effects of these chemicals may be quantitatively described in a way that makes use of bioassay data and scientific judgment on the extrapolation of the dose response relationship from animals to humans. The PCE analysis includes a comparison of control options to workers, service users, and the general public, showing the potential impact on health for each group and comparing expected health benefits to control costs. The value of better information to resolve health effect uncertainties is computed and compared to the cost of large-scale animal tests. The DEHP analysis illustrates an economic analysis of regulatory costs based on interproduct substitution among DEHP and competing plasticizers.

PART I

THE APPLICATION OF DECISION ANALYSIS TO TOXIC SUBSTANCES

Part I

CONTENTS

Section | Page

1 INTRODUCTION AND SUMMARY 1-1
"Unreasonable Risk" and the Toxic Substance Control Act 1-1
Decision Analysis as a Methodology for Dealing with Uncertainty 1-1
Project Purpose, Scope, and History 1-3
Summary of the Results of Literature Review 1-5
Summary of the Decision Analysis Methodology for Unreasonable Risk Determination 1-6
Summary of the Perchloroethylene Case Study 1-7
Summary of the Case Study of Di-Ethylhexyl Phthalate 1-9
Conclusions from the Case Studies on the Applicability of the Methodology 1-11

2 LITERATURE REVIEW 2-1
General Concepts 2-1
Risks and Benefits of Chemical Substances 2-14
Application to the Toxic Substances Control Act 2-25
Conclusions 2-30

3 DECISION ANALYSIS METHODOLOGY FOR UNREASONABLE RISK DETERMINATION 3-1
Overview 3-1
Nature of the Toxic Substances Problem 3-1
Purpose of a Decision Analysis Methodology 3-4
Outline of the Methodology 3-6
Coordination of Decisions 3-42
Summary 3-46

4 REFERENCES 4-1

Part I

FIGURES

Figure		Page
3-1	Components of a Decision	3-8
3-2a	Example Probability Density Function	3-17
3-2b	Example Cumulative Probability Distribution	3-17
3-3a	Example Probability Mass Function	3-19
3-3b	Example Decision Tree Probability Node	3-19
3-4	Illustrative Generic Decision Tree	3-20
3-5a	Decision Under Uncertainty	3-24
3-5b	Decision with Perfect Information	3-25
3-6	Decision Analysis Integration Model	3-28
3-7a	Simple Exposure Model	3-29
3-7b	Detailed Exposure Model	3-29
3-8	Illustrative Economic Network	3-31
3-9	Using Model to Calculate Uncertain Outcome	3-36
3-10	Relationship of Decision Tree and Integrating Model	3-37
3-11	Example Probabilistic Analysis for "Permit All Users" Alternative	3-39
3-12	Cumulative Probability Distribution on the Number of Cases of Cancer	3-40
3-13	Overview of a Coordinate Framework for Decision Making	3-44

TABLES

Table		Page
3-1	Example Sensitivity Analysis Results	3-34

Section 1

INTRODUCTION AND SUMMARY

"UNREASONABLE RISK" AND THE TOXIC SUBSTANCE CONTROL ACT

The American public has become increasingly concerned with toxic chemicals as a threat to human health and the environment. While Congress had previously passed legislation enabling the regulation of chemicals in food, in water, in solid waste, and in pesticides applications, the passage of the Toxic Substance Control Act (TSCA) in 1976 provided a comprehensive means for regulating the manufacture and use of chemicals in the United States. Under the language of the Act, the Administrator of EPA has a broad range of alternatives for imposing controls on the manufacturing and use of chemicals and for requiring that information on the potential toxic effects of the chemicals be provided to the federal government.

Most of these provisions of TSCA require a finding that the chemical substance or mixture in question presents or may present an "unreasonable risk" of injury to human health or the environment. The term "unreasonable risk" is not defined in the Act, and both the Act and its legislative history leave ambiguous the extent to which formal methods such as cost-benefit analysis, risk assessment, and decision analysis are appropriate for EPA to use in determining whether a chemical substance or mixture presents an "unreasonable risk."

DECISION ANALYSIS AS A METHODOLOGY FOR DEALING WITH UNCERTAINTY

This report presents the results of an investigation of decision analysis as a methodology that could assist EPA in regulatory decisions under TSCA. The methodology is also applicable to decision making by other regulatory agencies and by corporations or citizens whose decisions impact the extent and manner in which potentially toxic chemicals will be manufactured and used. The essence of the decision analysis approach is a recognition that the toxic impact of a chemical substance is typically uncertain.

The legislative history of TSCA suggests that determination of unreasonable risk involves a process of information gathering, analysis, and judgment that balances the probability of harm and the extent of the harm from the toxicity against the benefits of chemicals in use. The assessment of the probability of harm will rarely be possible on the basis of extensive statistical data, for such data rarely exist even for chemicals that have been widely used for many decades. In most decisions under TSCA, EPA must judge the probability of harm on the basis of such information as the effect of the chemical on laboratory animals and various cellular systems (e.g., Samonella typhimurium in the Ames test), the toxicity of similar chemicals, the extent of potential human exposure, and epidemiological data whose relationship to past chemical exposures are difficult to ascertain. The judgments required are therefore exceedingly complex, involve a wide range of scientific specialties, and require judgmental extrapolation from the limited data available to assess what might happen to human health and the environment in the absence of direct scientific evidence of harm.

Such extrapolation is inherently difficult and subject to various biases. Scientists and regulators have often advocated the use of conservative, "worst-case" assumptions as a way of ensuring that the extrapolation will be carried out in a consistent way, and that any errors introduced through the assumptions will be in the direction that increases protection for human health and the environment. However, it is often difficult to judge how much conservatism is appropriate. Subgroups within the population may be especially susceptible to toxic impacts or through unusual circumstances may be subject to unusually high levels of exposure. How far should regulators go in denying substantial benefits from the use of a substance to the public because the possibility exists that under some conceivable set of conditions the substance might induce harmful effects?

The methodology of decision analysis deals with uncertainty explicitly, rather than submerging the uncertainty by using "worst-case" assumptions. The "probability of harm" suggested in the legislative history may be assessed quantitatively as a summary of scientific judgment, and this probability assessment can be accompanied by the data and reasoning of the scientific experts whose judgment is being summarized. The use of mathematical modeling methods permits the overall probability of harm to be computed from probability judgments made on specific scientific issues, such as the appropriate form of a dose response relation or the appropriate formula for extrapolating from doses in laboratory animals to equivalent doses in humans.

PROJECT PURPOSE, SCOPE, AND HISTORY

In September of 1978, EPA issued a Request for Proposal for a project to investigate the use of risk-benefit methods to assist EPA decision making under TSCA. The contract was awarded to Decision Focus Incorporated and work began early in 1980. Initial tasks in the project included a review of the existing literature on methods for quantitative assessment of risks and benefits that would be applicable to toxic substances, and an exposition of the proposed methodology. The revised versions of the task reports constitute Section 2 and Section 3, the remainder of Part I of this report.

On the basis of extensive discussions with the EPA project technical officer and management within the Office of Pesticides and Toxic Substances, it was decided that the remainder of the project resources should be devoted to case studies illustrating the application of decision analysis to specific chemical substances. The specific chemical substances should be representative of the types of chemicals that would come up for regulatory decisions by EPA under TSCA. It was suggested that the case studies should emphasize the determination of unreasonable risk in situations where extensive information was already available about chemical toxicity and the extent of human exposure, but where EPA had not established specific proposed control options. The case studies would address situations in which EPA's regulatory decision would be a choice among control options rather than requirements for industry to carry out tests and submit information.

During the summer of 1980, the project team reviewed a number of lists of priority chemicals that were regarded as potential candidates for future regulation by the Office of Pesticides and Toxic Substances. Two classes of chemicals were selected: phthalate ester plasticizers and chlorinated solvents. During the fall of 1980, the case studies were narrowed to one chemical representative of each class: di-ethylhexyl phthalate (DEHP), the largest volume chemical among the phthalate ester plasticizers, and perchloroethylene (PCE), a chlorinated solvent widely used by the dry cleaning industry. In each case, the primary health concern was cancer, because recent data obtained by the National Cancer Institute indicated that exposure to these widely used chemicals could induce tumors in laboratory animals.

EPA and its contractors have carried out extensive analytical and information-gathering activities on both PCE and DEHP, and some of the resulting information and analysis was made available to our project. We also benefited from discussions with industry representatives and environmental groups, and we had some consulting assistance from Dr. Lee Husting of Environmental Health Associates, Berkeley, California, in the area of toxicology. However, most of the information for each case study was assembled from public sources by the authors. We did not attempt to assess judgmental probabilities from EPA scientists, and we did not participate in or interact with any EPA efforts to develop regulatory proposals for the two chemicals. The case studies are strictly intended as illustrative. Their sole purpose is to demonstrate how decision analysis methods might be used to quantify the degree of risk posed by exposure to a specific chemical, and how that risk might be changed by control options to reduce human exposure. The reader should draw no policy conclusions or implications regarding needed regulation from these case studies. Although the authors have summarized their insights from the analysis regarding the extent of the risk to human health posed by PCE, it should be recognized that the information in this report regarding both of the case study chemicals may differ in important respects from information currently available to EPA, and that no attempt has been made by the authors or EPA to obtain scientific peer review of the substantive scientific information. The case studies are intended solely as a vehicle for illustrating decision analysis methods that might at a future time be used to assist in reaching regulatory decisions. The authors believe that extensive scientific peer review of data, assumptions, and especially judgmental probabilities should be an essential part of any future applications of decision analysis methods to EPA regulation of specific chemical substances and mixtures under TSCA.

SUMMARY OF THE RESULTS OF LITERATURE REVIEW

Although there is an extensive literature on risk-benefit analysis, there is a lack of specific examples where analytical methods have been used as a basis for regulatory decisions on health or environmental hazards. There is general agreement in the literature that the role of analysis should be to organize information, not to provide a rule or formula that would determine the choice for the decision maker. The analysis should explicitly state the objectives and the feasible alternatives, and it should clearly separate value judgments from scientific information. Quantifying elements of the analysis can facilitate discussion and help in focusing debate on the relevant issues. Environmental legislation, executive orders, and court decisions have generally encouraged analysis, but have provided little guidance to regulatory agencies as to how analysis should be used in their decision processes.

Decision analysis may be regarded as an extension of cost-benefit or cost-effectiveness analysis to include an explicit, quantitative treatment of uncertainty. Like cost-benefit analysis, decision analysis frequently involves use of explicit quantitative values on outcomes such as environmental and property damage, mortality and morbidity, and aesthetic and political concerns. Mathematical modeling methods and sensitivity analysis can help to determine which of the many uncertainties and value issues are most important in determining the best decision alternative. Issues such as valuing human life, distributional effects, discounting, and quantification of uncertainty require close attention.

Risk-benefit analysis methodologies, particularly decision analysis, appear applicable to the regulation of toxic substances, but examples of such application are rare. Analysis can aid decision makers by organizing the available information, and making clear and explicit where assumptions and value judgments have been introduced. The application of risk-benefit analysis to chemical hazards is difficult because of the general lack of understanding of the toxicity of low levels of exposure and the pathways of exposure. However, because regulatory decisions must be made even in the face of uncertainty, it makes sense to use a method of analysis that deals with the uncertainty in a logical way rather than assert that uncertainty makes analysis impossible or useless. Progress has been made in developing methodologies to deal with the specific problems of implementing TSCA, namely, methodologies to determine unreasonable risk and to set priorities. However, much more development, refinement, and experience in applications appear to be needed before the methodology can be used as an operational framework to assist EPA decision making in determination of unreasonable risk and in setting priorities for allocating testing and regulatory resources.

SUMMARY OF THE DECISION ANALYSIS METHODOLOGY FOR UNREASONABLE RISK DETERMINATION

The decision analysis methodology consists of a conceptual framework within which to define a specific regulatory decision based on determination of unreasonable risk under TSCA, a mathematical model to assess the harm to human health and the environment and the costs of control alternatives that is tailored to the specific decision situation, and a process or series of steps for carrying out the analysis. Section 3 of Part I describes the conceptual framework, the model, and the analysis process in general terms and illustrates each of these aspects of the methodology with a hypothetical chemical substance.

The basic concepts of the decision analysis methodology include the definition of specific decision alternatives, the use of judgmental probability to quantify uncertainty, the explicit quantitative evaluation of health and environmental damage and costs of control alternatives, and the assessment of the value of additional information that reduces or removes uncertainty. The methodology is capable of addressing the difficulties of unreasonable risk determination: complex physical, biological, and economic interactions, numerous uncertainties, diverse impacted groups, and conflicting objectives. Key aspects of the analysis process include the development and use of models, sensitivity analysis, and explicit assessment of probabilities. The analytical process is iterative and can be applied at almost any level of detail, from a quick "back-of-the-envelope" calculation to fully disaggregated multiregional analysis using elaborate models to represent exposure pathways and economic substitution effects. The analysis is not static but permits new information to be factored in as it is obtained, and the value of developing more information can be estimated in a consistent manner. The concepts of decision analysis not only apply to individual decisions on toxic chemicals, they also can provide a basis for priority setting and coordination of decisions affecting many toxic substances.

SUMMARY OF THE PERCHLOROETHYLENE CASE STUDY

Perchloroethylene, sometimes called tetrachloroethylene and abbreviated PCE or PERC, is a solvent used for about 75 percent of the dry cleaning done in the United States. Dry cleaning accounts for about 50 percent of PCE consumption in the United States, other uses being metal cleaning, textile processing, and use as a chemical intermediate. PCE is not a new chemical, but rather one that has been in widespread use for decades. Its potential for liver damage and other acute toxicity effects in humans has been known for many years and is the basis for the current occupational standard of 100 parts per million of PCE vapor in the air. PCE has recently come under suspicion as a potential carcinogen. Its chemical structure is similar to a known human carcinogen, vinyl chloride. Short-term tests indicate that a commercial preparation of PCE is mutagenic, and there is some epidemiological evidence of higher cancer occurrence among dry cleaning workers. However, the strongest evidence implicating PCE as a carcinogen is a recent animal test carried out by the

National Cancer Institute (NCI), in which a sensitive strain of mouse showed a high incidence of liver tumors when fed PCE.

The case study presented in Part II uses the methodology of decision analysis to develop a quantitative description of the cancer risk posed by PCE to dry cleaning workers, users of dry cleaning services, and members of the public who live or work near dry cleaning plants. The case study examines a variety of control options that could reduce PCE emissions and human exposures, such as better maintenance and housekeeping to reduce spills and fugitive emissions, installation of carbon adsorption units to recover PCE vapor from the air, placement of dry cleaning machines in separate rooms, and use of combined dry-to-dry units instead of separate cleaning and drying machines.

The effect of such control options would be at most a modest increase in the cost of providing dry cleaning services. Options such as better maintenance and housekeeping appear to have a negative cost, because the saving from reduced purchases of PCE solvent more than offsets the cost of the maintenance and housekeeping procedures. A major benefit is reduction in exposure levels for dry cleaning workers. We have therefore formulated the analysis from the viewpoint of the dry cleaning industry. Costs of control options were assessed including taxes and tax credits. We introduced an explicit value judgment for the worth of avoiding a case of cancer, either among the workers, service users, or general public. This value judgment permitted determination of the best control strategy in the sense of maximizing benefits from avoided cancers less the costs of the control.

The impact of uncertainty in this case study is profound. We assessed uncertainty on the impact of PCE, not by requesting probabilistic judgments on whether PCE is a carcinogen, but by examining the judgments required to extrapolate from the results of animal experiments and other available scientific evidence to a projection of the incidence of human cancer that PCE exposure may induce. Based upon examination of the literature the following factors were identified as crucial:

- The basis for extrapolating dose in small laboratory animals to an equivalent dose in humans.

- Identification of the most appropriate laboratory animal to use as a model for cancer impacts in humans.
- The numerical basis for extrapolation of cancer incidence from high doses in laboratory animals to lower levels corresponding to human exposure.

For each factor, we have considered two alternative assumptions, giving a total of eight combinations. The effect of the alternative assumptions is great. Using conservative judgments (extrapolation based on surface area, most sensitive mouse strain as a model for man, linear nonthreshold dose response relation), the projected increase in national cancer incidence is about 350 cases per year. Under alternative, less conservative assumptions (extrapolation based on body weight, rat as the model for man, nonlinear dose response relation), the projected change in cancer incidence is nearly five orders of magnitude less, 0.01 cases per year. We therefore examined each combination of assumptions and developed a probability distribution over cancer incidence from probabilities assigned to the three crucial factors in the dose response relationship. From the decision context on control options, an illustrative calculation indicates it would be worth several million dollars per year to resolve this uncertainty by such means as large-scale bioassays of PCE. Such bioassays are in fact being carried out for PCE by NCI.

SUMMARY OF THE CASE STUDY OF DI-ETHYLHEXYL PHTHALATE

DEHP is a plasticizer, a substance that is combined with plastic resins to make flexible plastic products. About 190,000 metric tons of DEHP are produced and consumed annually in the United States, making it the most widely used single plasticizer. It is used in a variety of commercial and consumer products in which it has considerable economic value. It is not a new chemical and has been in use since the 1930s.

Because of the widespread use of DEHP, a large number of people are potentially exposed to it. Like other plasticizers, DEHP is not tightly bound to plastic products and can thus migrate out of the products during use or after disposal. Small amounts of DEHP have been found in many samples of food, water, and air. Because DEHP can bioaccumulate, it may be passed through the food chain. DEHP has also been found to leach from plastic blood bags and medical tubing such as that used in hemodialysis machines. Since the toxicity of DEHP is low, the observed concentrations and resulting human exposures are unlikely to have immediate health effects. However, in a recent study sponsored by NCI, DEHP was found to produce a significant number of liver tumors in rats and mice. Thus, EPA has examined possible human cancer risk for this chemical.

DFI carried out an illustrative calculation of the uncertainty in the human carcinogenic risk from DEHP using assumptions and methodology similar to that used for PCE. However, the calculations were based in large part on information from EPA internal draft documents. These data, particularly with respect to exposure, were later determined by EPA to be incorrect. At EPA's request, we have not included these calculations in this final report. After considering DEHP as a candidate for designation under Section 4(f) of TSCA, EPA concluded in early 1982 that no 4(f) funding with respect to DEHP was warranted [1,2].

The major focus of the DEHP case study is therefore the development and use of a prototype economic model of the plastics industry with emphasis on plasticizers and DEHP in particular. The model was developed to help analyze the economic implications of potential federal actions that might be taken to regulate the production or use of DEHP. The production of several different plastic resins, plasticizers, plastics, and their interactions in the marketplace are represented in the model. The model is a prototype in the sense that it is intended to provide first-order quantitative estimates of changes in market prices and quantities demanded and supplied at a national aggregate level of detail. These changes are difficult to determine, given the complex interaction of substitution among plasticizers. However, the prototype model illustrates such an estimate, and it could be refined to give better estimates.

The prototype model was run and solved for equilibrium quantities and prices for a base case and two regulatory policies. A consumer surplus calculation was used to estimate the economic impact of prohibiting or restricting the production and use of DEHP. A complete ban on DEHP would reduce consumers' surplus on the order of 100 million dollars per year. Eliminating the use of DEHP from medical applications and automobile interiors would have an annual loss of consumers' surplus on the order of three million dollars.

CONCLUSIONS FROM THE CASE STUDIES ON THE APPLICABILITY OF THE METHODOLOGY

The determination of whether the risk posed by a toxic chemical is unreasonable generally involves assessment of complex uncertainties. Although we support the use of quantitative estimates, the use of single number estimates such as those put forward by EPA's Carcinogen Assessment Group (CAG) is potentially misleading, for such estimates do not communicate any sense of the uncertainties to nontechnical decision makers. The use of confidence intervals derived from bioassay sample size is particularly misleading, since this source of uncertainty in projecting dose response relationships will often be much less than the uncertainty attending the basis for extrapolating from small animals to humans, the selection of an appropriate animal model, or the mathematical form of the dose response relationship.

Suppressing the uncertainty by invoking prudent assumptions is one basis for regulatory decisions. However, when widely desired products or services are involved and control will require large expenditures, judgments of prudence by scientists may be unacceptable as a means of determining public policy. A superior approach in our opinion is to portray the uncertainty explicitly and incorporate it into the basis for decision. We have illustrated this approach for PCE by calculating cancer incidence not just for one set of assumptions as CAG has done, but for alternative sets of assumptions. The methods of decision analysis involve assessment of probabilities over these alternative cases, permitting the calculation of a probability distribution on cancer incidence. By using the methods of cost-benefit analysis, which includes a monetary value on avoiding a case of cancer, one can then determine the best action in the face of uncertainty. Moreover, the decision analysis approach allows the calculation of what it would be worth to resolve the uncertainty. This calculation can be extremely useful for establishing priorities for costly information-gathering activities such as large-scale bioassays.

A frequent criticism of cost-benefit analysis is that distributional effects are suppressed. The PCE case study included calculation of the health impacts on various affected groups: workers, dry cleaning service users, and persons who live or work in the surrounding community. While we have chosen to value a case of cancer avoided as equal in each group, this assumption can easily be relaxed. Our calculations for PCE show the health impact as falling primarily on the workers and secondarily on the users of coin-operated dry cleaners. The risk to the neighboring public is much smaller by comparison.

Conceptually, the DEHP case study could have proceeded from the alternative estimates on cancer incidence for different sets of assumptions through to a probability distribution on cancer incidence for each affected group under each control option and a value of information calculation in the same manner as the PCE study. DFI and EPA concluded that it was not useful to carry a case study assessment of the health impacts of DEHP. To provide a meaningful illustrative calculation, we would have needed better definition of control options for DEHP and a pathway model linking the impact of emission reduction from the control to reduced levels in the environment, and especially in food. Developing such a pathway model was beyond the resources available to our project. Such models typically involve considerable uncertainty in the relation between specific sources of the toxic substance and the extent of concentration of the substance in the human diet, and the methods of decision analysis should be useful in developing and applying pathway models.

The DEHP case study therefore focused on the economic consequences of potential regulation. DEHP is typical of a chemical intermediate, and the consequences of restricting its use are complicated to assess. Many substitute plasticizers are available at modest additional cost among the phthalate esters and other classes of chemicals, and both DEHP and its substitutes can be used in a wide variety of plastics products. How does one evaluate the economic impacts of regulation in such a complex market situation, which is typical of many potentially toxic chemicals? Using existing software developed by DFI for analysis of energy markets, we constructed a prototype economic model of the plastics industry with emphasis on plasticizers, particularly DEHP. The model explicitly represents plasticizers, resins, and plastics production processes; market competition; and changing demand patterns. Modeling approaches of this level of detail are needed for EPA to assess the costs imposed on the industry and on consumers by regulations that change chemical use patterns within a complex market.

The analytical methods presented in the two case studies should be viewed as illustrative of applications that must be tailored to the specifics of the regulatory decision situation and the scientific information available. If analysis using these methods is to be used as a basis for public policy decisions, it should receive review and careful scrutiny from the scientific community through such mechanisms as the EPA Science Advisory Board. Probabilities such as those we have assessed for PCE on factors in the dose response relationship should represent a judgment agreed upon by qualified scientists, and the basis for such a judgment should be documented and be available for review.

The decision analysis approach presented in this report is not necessarily elaborate computationally or expensive to carry out. The largest expense is in assembling the information. We expect that the methods illustrated in the case study for PCE could easily be adapted for many other chemicals of concern because of their potential carcinogenicity. We would expect that the conclusions for such analysis would be similar: If there is widespread human exposure and even a small probability that the chemical is a carcinogen, information gathering by means such as large-scale bioassays will have large expected benefits that more than offset the costs.

The analysis presented in the PCE case study was not representative of many substances that are candidates for regulation under TSCA. Human exposure to PCE is well documented. Relatively good data and predictive models for exposure are available. Such information will not be available for new chemicals, especially where complex environmental pathways to people are involved. PCE does not bioaccumulate significantly, whereas many toxic chemicals do. For such chemicals, assessment of uncertainty on human exposure might be as complex as or more complex than the assessment of uncertainty we have presented on the health impacts of PCE.

The DEHP case study illustrates that assessment of economic impacts of regulation can involve elaborate and sophisticated calculations, which will typically be needed when substitution effects in complex markets must be assessed. Similarly, evidence of bioaccumulation potential and recognition that ingestion through food is the leading route for human exposure might motivate development of an elaborate and sophisticated pathways model for DEHP and for other chemicals with significant bioaccumulation potential. The development and use of large models is consistent with decision analysis. Large models are in fact a necessary part of the decision analysis process when sensitivity analysis indicates that the additional detail in the scientific information that these models embody is important for regulatory decisions.

Decision analysis provides a potentially useful framework for EPA for addressing the complexity and uncertainty in the potential harm to human health and the environment posed by chemical substances. It does not provide an easy route to regulatory answers, but rather a framework for integrating the available scientific information together with value judgments from policy makers to achieve a consistent set of decisions. Use of decision analysis methods requires skillful tailoring of the methodology to the application, and EPA will need to acquire the needed skills through experience. The accomplishments of this project should encourage further experimental applications of decision analysis to chemical regulatory problems. As decision analysis methods are perceived by policy makers and the scientific community as providing an improved basis for regulatory decisions, the use of these methods should increase.

Section 2

LITERATURE REVIEW

The primary purpose of this section is to review and summarize the literature on risk-benefit analysis and priority setting as applied to toxic substances. A second purpose is to provide a background for the analysis methodology presented in Section 3. By risk-benefit analysis we mean the general field of analysis that attempts to balance costs and benefits or risks and benefits. We mean it to include the methods known as cost-benefit analysis, cost-effectiveness analysis, and decision analysis, each of which is defined in the section on specific methodologies. Since the entire body of literature on risk-benefit analysis is vast and has been reviewed many times before, our discussion will cover only the most pertinent works. Additionally, rather than present individual reviews, we present a review organized by topic, starting with a discussion of general concepts, followed by a discussion of chemical risks and the implementation of the Toxic Substances Control Act (TSCA).

GENERAL CONCEPTS

Although there are a number of approaches to risk-benefit analysis, many of the general concepts are common to the different approaches. We begin this subsection by discussing the role of analysis in decision making and the characteristics of analysis recognized as desirable. We then discuss features of several analytical approaches, methodological issues that require close attention, and institutional issues related to the use of risk-benefit analysis.

Role of Analysis in Decision Making

It is generally recognized that the role of analysis should be to organize information for use by politically responsible decision makers and to help focus public discussion on the relevant issues. As stated by Harold Green:

> The object of risk-benefit assessment should be to produce data for use in political discussion and debate, to elevate the level of such discussion and debate, and to inform and enlighten, but not control, those who are charged with responsibility for making decisions in the public interest ([3],p.290).

A similar view was expressed by the National Research Council in its report Decision Making for Regulating Chemicals in the Environment [4].

> Benefit-cost analysis, at least as we use the term, is not a rule or formula which would make the decision or predetermine the choice for the decision maker. Rather, it refers to the systematic analysis and evaluation of alternative courses of action drawing upon the analytical tools and insights provided by economics and decision theory. It is a framework and a set of procedures to help organize the available information, display trade-offs, and point out uncertainties. In this way benefit-cost analysis can be a valuable aid; but it does not dictate choices, nor does it replace the ultimate authority and responsibility of the decision maker ([4],p.39).

Thus, although analysis can be useful in the regulatory decision-making process, analytical results do not dictate the regulatory choice.

Desirable Characteristics of Analysis

A number of desirable characteristics of analysis have been identified in the risk-benefit literature. According to the National Research Council in its report Decision Making in the Environmental Protection Agency [5], an analysis should explicitly state the objective and feasible alternatives, as well as identify the possible outcomes of EPA action and the uncertainties associated with those outcomes:

> EPA's decisions on standards and regulations should be supported by analyses that explictly state the objectives of the decisions, identify feasible alternatives, evaluate (quantitatively, to the extent possible) the consequences of each alternative decision, explore potential problems in implementation, and indicate and examine the degree of uncertainty about the effects of EPA actions. The analysis should be available to the public ([5],p.10).

Another important characteristic of analysis is the clear identification and separation of value judgments from objective statements of information. The National Research Council has recommended:

> Value judgments about noncommensurate factors in a decision such as life, health, aesthetics, and equity should be explicitly dealt with by the politically responsible decision makers and not hidden in purportedly objective data and analysis ([4],p.10).

The need to separate the scientific information from the value judgments in arriving at a basis for decision is a major theme of William Lowrance's book, Of Acceptable Risk: Science and the Determination of Safety:

> Failure to appreciate how safety determinations resolve into the two discrete activities...gives rise to the false expectation that scientists can measure whether something is safe. They cannot, of course, because the methods of the physical and biological sciences can assess only the probabilities and consequences of events, not their value to people....Deciding whether people, with all their peculiarities of need, taste, tolerance, and adventurousness, might be or should be willing to bear the estimated risks is a value judgment that scientists are little better qualified to make than anyone else ([6],p.9).

Most authors also believe that it is desirable to quantify as many of the elements of analysis as possible. Quantification facilitates discussion and focuses debate on the relevant issues. However, "Quantification is not an end in itself, but is rather a means to make the reasoning behind a regulatory decision clear and explicit" ([7],p.6).

Finally, it is desirable to have systematic procedures for processing information. As stated by the Conservation Foundation:

> Somehow the information must be analyzed and synthesized. This may be done intuitively, if the decision maker chooses to focus on only a few of the relevant factors. But ideally this process should be approached more systematically and predictably ([7],p.9).

To summarize, analysis should contain explicit statements of alternatives, information, and values; it should contain quantitative elements to the extent feasible; and it should contain a systematic procedure for organizing the elements.

Specific Methodologies

We now present a brief review of three methodologies: cost-benefit analysis, cost-effectiveness analysis, and decision analysis. Although each methodology was developed from a slightly different point of view, many of the specific techniques are similar. In applying each methodology, there are fundamentally difficult issues, such as valuing noneconomic effects and describing distributional effects of regulation. These difficulties are discussed in later paragraphs.

Cost-Benefit Analysis. Cost-benefit analysis (Prest and Turvey [8], Hill [9], Mishan [10]) has been widely used in the public sector, particularly by federal agencies such as the Corps of Engineers. It is most often used to choose an alternative for a specific project and is less easily applied to regulatory decisions. Cost-benefit analysis is based on maximizing economic efficiency, with the assumption that maximum social welfare will thus be realized. It attempts to take into account all costs and benefits to all groups in society, whether incurred directly or not.

The major limitation of the approach is that all outcomes to be included in the analysis must be specified in monetary terms or must have monetary value imputed from an appropriate market. In essence, it is assumed that society's preferences are expressed by the monetary values placed on goods and services. This is a standard assumption of welfare economics, and while it may be appropriate in some cases, it runs into trouble when dealing with regulatory decisions, where many of the outcomes are not subject to market pricing. Hill summarizes the approach and suggests some of the problems:

> ...cost-benefit analysis can be conceived as a process whereby a public agency in pursuit of economic efficiency allocates its resources (land, labor, and capital) in such a way that the most 'profitable' projects are executed and developed to the point where marginal benefits equal marginal costs. Thus the last dollar invested in a project brings a marginal economic return at least as high as that possible were the funds spent in some other way. However, so direct an extension of the private allocation model to allocation in the public sector raises a number of problems. The private and public models are analogous only if

> (1) no barriers exist to the flow of funds and resources, (2) benefits and costs can be determined at competitive prices, (3) there are no external economies or diseconomies, and (4) no other external effects exist ([9],p.19).

Hill goes on to point out that such conditions rarely exist in the public sector, noting that "the existence of a public sector in a free enterprise economy is justified, in part, by the absence of these very factors" ([9],p.19).

Despite the problems and limitations, however, cost-benefit analysis is being widely advocated as a means of improving regulatory decisions. The recently released report of the Toxic Substances Strategy Committee (TSSC) recommends a federal effort to improve methods for estimating costs and benefits and for evaluating their relative importance:

> A shortcoming in federal regulation of toxic substances is the failure to improve analytical methods for developing cost-benefit information and for using it as appropriate, as one of several tools in regulatory decision making despite the inherently limited analysis. Improvements in analytical methods will help the agencies to select consistent and cost effective ways to reduce risks ([11],p.101 and p.xxxiii).

Cost-Effectiveness Analysis. Cost-effectiveness analysis is similar to cost-benefit analysis, except that usually a goal is specified and analysis is performed to determine the least-cost (most cost-effective) means of achieving that goal. One possible advantage of this approach is that only the costs and not the benefits have to be quantified. An example of cost-effectiveness analysis would be the examination of the least-cost method of achieving a prespecified pollution emission standard, in which the costs of meeting the standard are estimated but no attempt is made to quantify the benefits. Some shortcomings of this approach as applied to TSCA were identified by the Conservation Foundation:

> Determination of whether risk posed by a chemical is unreasonable involves choosing among goals, and therefore cost-effectiveness analysis does not help to provide an answer. It may be useful in choosing among alternative regulatory techniques (prohibition of uses versus volume limitation, for example), once the decision about level of control has been made. However, it should be kept in mind that, even when the goal has been unambiguously specified

> cost-effectiveness analysis poses the same problems in quantifying and aggregating factors that cost-benefit analysis does ([7],p.34).

Decision Analysis. Decision analysis (Howard [12,13,14], North [15], and Raiffa [16]) combines the concepts of decision theory with the modeling techniques of systems analysis. Decision theory provides the basis for the analysis of uncertainty and values of the decision maker, while the use of explicit structural models gives decision analysis the power to cope with complex interactions and dynamic behavior. An example of decision analysis applied to sulfur oxide emission control is given by North and Merkhofer [17,18]. Other examples include Howard et al. [19] and Keeney and Robilliard [20].

One of the main features of decision analysis is the explicit incorporation of uncertainty into the risk-benefit calculations. As stated by the National Research Council:

> Decision analysis does not supplant or make unnecesary other methods of analysis such as cost-benefit analysis or cost-effectiveness analysis. Rather, decision analysis should be looked upon as a technique for incorporating uncertainty into these other forms of analysis ([5],p.226).

And as concluded by the Conservation Foundation:

> Given that a high degree of uncertainty surrounds most of the components of decisions about toxic chemicals and that decision analysis provides the best set of analytical tools for dealing with uncertainty, the application of such analysis to TSCA decisions clearly warrants examination ([7],p.34).

Decision analysis employs a quantitative description of the probabilities and values for the consequences or outcomes that may result from each of the decision alternatives. Assessment of the probabilities and consequences may be carried out directly by encoding the judgment of experts or indirectly through the use of structural models to predict the consequences or outcomes of concern.

A structural model is a mathematical representation of how various physical, biological, and economic factors relate to or determine outcomes such as morbidity and mortality; damage to nonhuman species; and economic welfare of consumers, producers, and workers. In an environmental application of decision analysis such as [18], models may be used to describe the relation of emissions to output of economic goods and services, dispersion and conversion of emissions through environmental pathways to reach receptors, dose response relationships, and economic impacts of controls. The structural models make it possible to incorporate explicitly complex information on causal and statistical relationships in assessing probabilities on outcomes.

Decision analysis frequently involves use of explicit quantitative values assessed on outcomes such as environmental and property damage, mortality and morbidity, and intangible issues such as aesthetic and political concerns [18,19]. The central advantage of this practice is that it allows sensitivity analysis to be carried out to determine which of the many uncertainties and value issues are most important in determining the best decision alternative. The efforts of the analysts and the attention of the decision maker may then be focused on these issues. Calculations of the value of resolving uncertainty require explicit quantitative value assessments; these calculations are often useful in providing insight on the desirability of gathering further information from research programs [18,19].

Issues That Require Close Attention

At least four issues associated with risk-benefit analysis have been identified in the literature as requiring close attention: valuing human life, describing distribution effects, specifying preferences over time, and quantifying uncertainty.

Value of Life. Three main approaches have been taken to the problem of determining what resources should be devoted to reducing statistical risks to human life. The first is an attempt to place a dollar value on the life that is lost through the concept of "human capital" ([5],p.233). Human capital is the present value of an individual's projected future earnings taking into account the age, sex, and education of the particular individual. A major problem with this approach is that is does not reflect social attitudes toward life. For example, its use implies that retired people or those unable to work would have no value to society.

An alternative that avoids the problem of assigning a value to life is determining an individual's "willingness to pay" for a certain reduction in risk ([5],p.235). The amount that should be spent on a risk-reducing project would then be the sum of the amount each individual would be willing to pay. Of course, determining this amount may be difficult; some authors have maintained that the determination can be accomplished through questionnaires or by observing pay differentials for jobs that pose higher than average risks ([5],p.236 and [21],p.138).

The third method of valuing risk reductions, developed by Howard [22], involves the concept of "small-risk value of life." This method is based on the ethical view that each individual has the right to make or delegate decisions that affect his or her life. Most individuals would choose to make their own decisions when high risks are involved and might choose not to take some risks, such as playing Russian roulette, even if offered arbitrarily large sums of money. However, for decisions involving small risks, on the order of one chance in 10^{-4} or smaller, an individual might choose to delegate those decisions to his or her agent (e.g., the government), who would use that individual's small-risk value of life in the expected value sense to determine the best alternative.

The implication of the "small-risk value of life" approach is that the judgment of the appropriate tradeoff between probability of death and monetary gain or loss is a subjective choice by the individuals affected. The value of life is not a quantity susceptible to "objective" measurement by economists or scientists. The monetary value ascribed by an individual to reducing his or her probability of death will vary from individual to individual; the value will depend on the individual's health, assets, attitude toward risk, and many other factors. The process of making explicit judgments on the tradeoff between money and risk makes many people uncomfortable, but decisions implying such judgments are being made constantly both by individuals and by public officials with responsibility to protect public health and safety.

Distribution Effects. A number of authors have pointed out that the concept of economic efficiency ignores important distributional effects that governmental regulations may impose. As noted by the Conservation Foundation:

> It is important for the decision maker to have information about how costs and benefits are distributed among various sectors of the population (e.g., workers, direct consumers of products containing the substance, general urban populations, etc.). In particular, he should consider whether both the costs and the benefits accrue to the same sectors, or whether some receive the benefits, while others bear the cost ([7],p.13).

An example of such a distributional effect would be an action that resulted in the closing of an industrial plant. From the point of view of society as a whole, if there is full employment, the closure may not be a cost, since workers may find employment elsewhere and the capital in the plant may be put to use elsewhere in the economy. However, from the point of view of the workers and the community in which the plant was located, the costs may be great.

Distributional effects such as these involve multiparty interactions, which are traditionally the concern of game theory [23] and social choice theory [24]. Although these analytical areas are not highly developed in practical applications, they indicate that one potentially valuable way to address distribution effects is to identify clearly the consequences to each party and then let them use that information to come to a resolution by political or legal means. (For a discussion of multiparty decision analysis see [25].)

Time Preferences and Discounting. Discounting is a traditional method of comparing and aggregating costs and benefits that occur at different points in time. In dealing with strictly economic costs and benefits, it may be appropriate to discount cost and benefits by a "private opportunity rate," which corresponds roughly with market interest rates ([5],pp.237-238). However, the application of discounting in the context of chemical regulation can cause considerable difficulties:

> For example, if the discount rate were 5 percent, 100 cases of poisoning 75 years from now would be equivalent to about 3 cases today; or 1 case today would be valued the same as 1,730 cases occurring in 200 years, or the same as the current world population (more than 3 billion cases) in 450 years. Clearly, intergenerational effects of these magnitudes are ethically unacceptable, yet they might be made to appear acceptable if the traditional social rate of discount concept were applied. There is as yet no generally accepted method for weighing the intergenerational incidence of benefits and costs ([4],p.43).

To overcome these problems, it has been proposed that time preferences involving intergenerational effects be recognized as value judgments and, whenever possible, they should be addressed directly by assigning present values to future impacts rather than through a discount rate. (See [26], p.62 and [27].)

Uncertainty. A fundamental characteristic of risks and benefits is that their quantification contains many uncertainties. These uncertainties arise from a lack of knowledge in the mechanisms of the risk (e.g., the relationship between exposure to a chemical and the effect on health) and the economics associated with the benefits (e.g., the availability of adequate substitutes for a particular chemical). However, regulatory agencies are confronted with the necessity of making decisions, including the alternative of doing nothing. Therefore, the assessments of risks and benefits must be made in spite of the uncertainties. In describing the estimation of cancer risks, the Interagency Regulatory Liaison Group (IRLG) has stated:

> Because extrapolations are involved, uncertainties are necessarily attached to the cancer risk estimates that can be made with current methodologies. Furthermore, uncertainties arise from other sources, particularly from attempts to identify accurately conditions and levels of exposure of the human group or individual. Despite the uncertainties, risk estimates can be and are being made not only by some regulatory agencies but by other scientific bodies ([28],p.39871).

In a recent report, the Office of Science and Technology Policy (OSTP) recommended that uncertainties be included in risk estimates in the first stage of a two-stage decision-making process:

> Characterization of the overall risk for humans in quantitative terms should be the final step in the stage I process. The characterization should use the most likely value for each term in the risk equation and should include an appropriate representation of uncertainty ([29],p.174).

A solution to the problem of representing uncertainty is suggested by decision theory. As stated by the National Research Council:

> One of the contributions of decision theory is to show how probabilities can be used to quantify uncertainties. People are accustomed to hearing probabilities of rain in predictions of tomorrow's weather or odds on forthcoming elections and sporting events. The same concepts may be used to describe uncertainties related to toxic substances. An example of such a probability statement would be: "There is a 90 percent probability that the chemical will produce no increase in the incidence of cancer, and a probability of 5 percent is assigned that the chemical is weakly carcinogenic and would result in an annual increase of 1 to 100 additional deaths from cancer. A 5 percent probability is assessed that the compound is strongly carcinogenic in man and at least 100 deaths from cancer would result from each year of unrestricted use" ([4],pp.43-44).

The source of these probabilistic estimates can be either the decision maker himself or experts in a particular field. Slesin and Sandler [30] advocate the use of chemical categorization systems to help scientific researchers assign probabilities to the likelihood that a chemical causes cancer:

> In the analysis of vinyl chloride analogs, for instance, we suggested several different structure-activity categorization schemes, each based upon a different family of potential carcinogens. Given present knowledge, researchers can assign different subjective probabilities to the likelihood that an untested analog, a member of one of the several possible categorical families, causes cancer or is otherwise toxic ([30],p.389).

To help quantify these probabilities, analysts can use procedures for encoding probabilities as described by Spetzler and Stael von Holstein [31] and Tversky and Kahneman [32,33]. EPA is currently sponsoring a review of the rich literature on encoding probabilities in the context of possible use of decision analysis methods in setting ambient standards for criteria air pollutants [34].

Legal and Institutional Basis for Using Risk-Benefit Analysis

The legal basis for performing risk-benefit analysis comes from three sources: legislation, executive orders, and court decisions. Here we briefly review these sources as they apply to the regulation of toxic substances.

Legislation. There is a wide range of approaches to the use of cost-benefit or risk-benefit analysis in environmental legislation. The most restrictive is the Federal Food Drug and Cosmetic Act, which requires a ban of any food additive that is found to be carcinogenic in animals regardless of the benefits [35]. At the other extreme is TSCA, which specifically requires tradeoffs of risks and benefits. Under TSCA, EPA must consider and make findings on

> ...the effects of such substance or mixture on health and the magnitude of the exposure of human beings to such substance or mixture, the effects of such substance or mixture on the environment and the magnitude of the exposure of the environment to such substance or mixture, the benefits of such substance or mixture for various uses, and the reasonably ascertainable economic consequences of the rule, after consideration of the effects on the national economy, small business, technological innovation, the environment and public health [36].

However, actual procedures for making tradeoffs are not included in TSCA or in other environmental legislation. As stated by Baram:

> Congress has frequently called upon the regulatory agencies to consider and balance multiple societal objectives in their decision-making, but has usually failed to provide guidance as to how agency discretion on such substantive matters is to be structured. At its most basic level, the necessary guidance would address the relative importance of the various factors to be included in the balancing process; the classic problems of valuation, discount rates and distribution; and the analytical framework to be used to reach decisions ([37],p.49).

Thus, Congress may permit or even encourage the use of risk-benefit analysis but leaves a great deal of discretion to the implementing agency.

Executive Orders. Both the Ford and Carter administrations have issued executive orders requiring federal agencies to assess the economic impacts of major regulations and rules issued by them. Under President Ford's Executive Order 11821, amended by Executive Order 11949, federal agencies were required to prepare "inflationary impact statements" for all major legislative proposals, regulations, and rules. Similarly, President Carter's Executive Order 12044 required that "regulatory analysis" be performed in developing regulations. The analysis must include careful examination of alternative approaches early in the decision-making process:

> Each regulatory analysis shall contain a succinct statement of the problem; a description of the major alternative ways of dealing with the problem that were considered by the agency; an analysis of the economic consequences of each of these alternatives and a detailed explanation of the reasons for choosing one alternative over the others [38].

Executive Order 12291 issued at the beginning of the Reagan Administration sets forth the general requirements that:

> (Section 2b) Regulatory action shall not be undertaken unless the potential benefits to society for the regulation outweigh the potential costs to society;
>
> (Section 2c) Regulatory objectives shall be chosen to maximize the net benefits to society;
>
> (Section 2d) Among alternative approaches to any given regulatory objective, the alternative involving the least net cost to society shall be chosen; and
>
> (Section 2e) Agencies shall set regulatory priorities with the aim of maximizing the aggregate net benefits to society, taking into account the condition of the particular industries affected by the regulations, the condition of the national economy, and other regulatory actions contemplated for the future ([39],p.13193-4).

Thus, executive orders have reinforced the legislative requirements for risk-benefit analysis and have tended to emphasize the economic consequences of regulation.

Court Decisions. Several recent court decisions have shaped the use of risk-benefit analysis. In the recent cotton dust case [40], the court upheld standards that were based on a logical analysis of the best available information and rejected standards that were not supported by analysis. In an earlier case, Ethyl Corporation v. EPA [41], the court "expressly held that hypothetical and other forms of scientific evidence not reaching the level of certainty were relevant to a judgment of risk posed by chemicals" ([30],p.387). In Reserve Mining Company v. EPA, the court supported the use of hypothetical evidence to predict risk. The court stated:

> These concepts of potential harm, whether they be assessed as "probabilities and consequences" or "risk and harm," necessarily must apply in a determination of whether any relief should be given in cases of this kind in which proof with certainty is impossible [42].

The recent Supreme Court cases on the Occupational Safety and Health Administration (OSHA) proposed benzene and cotton dust standards have been regarded as important legal tests on the need for cost-benefit analysis in regulation of toxic chemicals. In the cotton dust decision, the court held that cost-benefit analysis is required only if explicitly stated in the law [43]. In particular, OSHA is not required to perform such analyses. Neither decision, however, provided clarification of the Court's position on use of cost-benefit analysis, treatment of uncertainty, or definition of "significant risk" [43,44].

In summary, the courts have generally supported the use of risk-benefit analysis and the use of probabilities to specify risks, but the courts have provided EPA and other regulatory agencies with little specific guidance on how risk-benefit analysis should be used in their decision processes.

RISKS AND BENEFITS OF CHEMICAL SUBSTANCES

Since World War II, the American chemical industry has produced a proliferation of chemicals that have contributed to our standard of living.

Pesticides and food additives have helped to produce a "cornucopia of diverse prepared foods and foodstuffs made independent of local growing seasons or of climate by safe transportation over long distances" ([45],p.5). Synthetic drugs have contributed to the treatment of disease, and a vast array of chemical products such as plastics have made life easier and more productive. Toxicological testing for acute effects has long been an accepted industry practice, but adverse chronic effects are considerably more difficult to determine, especially when a long latency period may be present. In recent years there has been an increasing level of public concern for potential adverse health and environmental effects from chronic exposure to manufactured chemicals. As stated by Philip Handler:

> Growing knowledge of the biology of cancer and the diversity of chemical structures capable of eliciting a neoplastic response in laboratory animals--together with the thalidomide episode, which demonstrated that a substance which successfully passed the screen of assays for acute toxicity could, nevertheless, have disastrous long-term effects--gave rise to concern for possible consequences of chronic exposure to low levels of diverse materials ([45],p.5).

The essence of risk-benefit analysis of chemicals is thus the estimation of the risks from chronic exposure, an estimation of the benefits, and a balancing of risks and benefits. Handler proposes a sensible approach to this balancing:

> A sensible guide would surely be to reduce exposure to hazard whenever possible, to accept substantial hazard only for great benefit, minor hazard for modest benefit, and no hazard at all when the benefit seems relatively trivial ([45],p.8).

In this subsection, we summarize the current state of the art in estimating risks and benefits of chemicals. In the following subsection, we describe some suggested approaches to the balancing process and the problem of setting priorities in the context of the Toxic Substances Control Act.

Characteristics of Chemical Risks and Benefits

Chemical risks and benefits have some characteristics that distinguish them from other types of risk-benefit problems. Page [46,47] has identified at least five characteristics: ignorance of mechanism, potential for catastrophic costs, relatively modest benefits, low probability of catastrophe, and difficulty of detecting adverse effects. A sixth characteristic, which is really a consequence of the above five, is the difficulty of establishing that a chemical is safe.

Ignorance of mechanism may apply to a number of stages that relate the manufacture and use of a chemical to an adverse health or environmental impact. Either the chemical or a byproduct of chemical manufacture may possess the toxic effect. The pathway linking the receptor to the emission is typically complex and often poorly understood. A chemical such as mercury may be released at a low concentration, transformed by microorganisms into a more toxic form (methyl mercury), and concentrated in the aquatic food chain. Very little knowledge is available on the biochemical mechanisms that lead to cancer, birth defects, or chronic health impairments, so that dose response relationships must be inferred from epidemiological investigations or extrapolations from animal experiments that are typically carried out at very high dose levels.

A potential for catastrophic costs arises when a chemical can be introduced on a massive scale over a time that is short compared to the latency period for adverse effects. Thus, many people may be exposed to irreversible adverse effects before the damage becomes apparent and regulation can be imposed. The increase of lung and other cancers followed by several decades the increase in smoking, first in men and then in women. A food additive or consumer product (e.g., flame-resistant children's sleepwear) could in principle expose a large number of people to a chemical that later turned out to be a carcinogen, with the result that an epidemic of cancer, birth defects, or chronic impairment occurs in the affected group. Such epidemics have indeed occurred on a limited scale with drugs (thalidomide, diethylstilbestrol) and with chemicals in the workplace (vinyl chloride, beta naphthalamine, bischloromethylether, asbestos).

Measured against the potential for catastrophe, the benefits of the chemical may appear relatively modest. However, when substitutes are not readily available, the judgment of risks versus benefits may be difficult. When the accumulated scientific evidence indicated that increasing levels of fluorocarbons in the atmosphere might deplete the ozone layer, use of fluorocarbons as aerosol propellants was quickly banned. However, fluorocarbons continue to be used as refrigerants, in part because good substitute refrigerant materials do not exist. Many persons regard food colorings as providing little benefit. The benefits of saccharin compared to its risk as a carcinogen have been the subject of intense public debate [48].

A fourth characteristic of chemical risks is the low probability of the catastrophic outcome. In fact, most chemicals do not cause cancer, birth defects, or other serious and potentially widespread toxic effects:

> For many potentially toxic chemicals, and for nuclear power, ozone depletion, and recombinant DNA, what little is known about mechanism suggests that the probability of the catastrophic outcome is low, much lower than the probabililty of the favorable outcome ([46],p.210).

Even though the potential loss from the catastrophic outcome may be far greater than the benefits, the low probability of the catastrophic outcome may make the problem more evenly balanced in the judgment of the public and the officials who must assume responsibility for regulatory decisions.

The fifth characteristic is the difficulty of detecting adverse effects:

> As a general observation, it appears that for many toxics problems, adverse effects, when they exist, are hidden with the consequences that even expensive, well designed tests have low probabilities of discovering effects when they exist ([47],p.10).

Detecting low-potency carcinogens is particularly difficult. For example, consider an animal test for carcinogenicity for which there are 50 animals in the control group and 50 in each of several treated groups. If the significance level is set at 5 percent--that is, there is a 5 percent chance the test will give a false positive reading--then there can be up to a 50 percent chance that the test will not detect an effect when it is actually present ([47],p.8).

A consequence of the difficulty of detecting an adverse effect is the difficulty of establishing that a chemical is safe. After examining the methodological difficulties of epidemiology and the low sensitivity of animal bioassays, Leape concluded that neither procedure could ever "provide conclusive proof that a substance is not carcinogenic" ([49],p.92). William Clark [50] has compared regulation with medieval witch hunting. Once a suspect witch (or a suspect chemical) has been accused, it is impossible to assemble enough evidence to conclusively establish innocence. A potentially serious consequence of the difficulty of proving a chemical not toxic is that too much attention may be focused on relatively unimportant chemical risks that have previously been identified, while more serious risks continue to go unrecognized.

All of these characteristics of chemical risks taken together result in a complex risk-benefit problem. However, the need for regulatory decisions requires approaching the complexities and uncertainties with as much logic and analytical skill as possible.

Chemical Toxicity

A key element in the risk-benefit analysis of chemicals is the toxicity of the chemical under consideration. Estimates of toxicity for a particular chemical can be derived from toxicity tests and from comparisons with chemicals of similar structure and known toxicity. In this section we summarize the characteristics and limitations of toxicity tests, describe the use of chemical structure, and point out some of the difficulties in predicting human response to various levels of chemical concentrations (dose response).

There are many hazards to human health from toxic chemicals. Chronic neurological damage, mutations, birth defects, cancer, and many other adverse health impacts may be caused by chemical substances. Most discussions of toxicity emphasize cancer, for reasons that were articulated in the TSSC report:

> ...cancer captures the most public attention because it is prevalent, it is often irreversible, it is poorly understood, and it is a disease that often involves considerable pain and suffering. Many substances that cause cancer have other toxic effects ([11], p.116).

Our discussion will therefore emphasize testing for carcinogenicity; it should be recognized, however, that a much wider range of health effects may be of concern in assessing the risks from toxic substances.

Toxicity Testing. There are three main types of toxicity tests: epidemiologic studies, animal bioassays, and short-term tests (usually tests of single cells). Each type of test has its advantages and disadvantages, and each can contribute to the overall assessment of toxicity.

Epidemiology is the study of the correlations between disease rates and environmental factors in a human population. Epidemiological studies for cancer are usually of two types: "cohort" studies and "case-control" studies. Cohort studies compare groups differently exposed to a suspect substance for differences in disease rates. Case-control studies compare those who contract a certain type of disease with those who do not to identify differences in their environmental conditions ([49],p.92).

Epidemiology is generally considered to be the soundest basis for determining cancer risks to humans ([51],p.1200). However, epidemiology has many limitations:

> Theoretically, as direct evidence of human response, epidemiology can offer compelling evidence of carcinogenicity and the magnitude of the risk to humans posed by a particular substance. Unfortunately, epidemiology at best is a crude science. A variety of factors may enhance or disguise the actual effect of a carcinogen. A scientist is unlikely to discover whether a population was exposed to substances which enhance or inhibit the response to the studied carcinogen. Nor can the scientist estimate precisely the degree to which demographic differences are responsible for differences in the cancer rates of the observed groups ([49],p.92).

One difficulty is in quantifying the potency of a potential carcinogen:

> But even when epidemiology indicates that a substance causes cancer, it often cannot measure the potency of that substance. It is simply too insensitive and imprecise. The scientist cannot control the conditions of exposure, and therefore cannot isolate the effect of the suspected carcinogen for precise measurement. Nor can he or she determine, in most cases, the level of exposure of the sample population to a given substance, since information on ambient concentrations, or even on emissions, is often crude or completely unavailable ([49],p.92).

Furthermore, epidemiologic evidence is available only after years of exposure to an identifiable group of people such as smokers or workers exposed to a particular chemical. Because of these limitations, there are only 82 chemicals for which there is some epidemiological evidence of human carcinogenicity ([51],p.1201). Clearly, other methods for determining toxicity must also be used.

Because of the inherent difficulties of epidemiology, long-term animal bioassays are most often used for regulatory purposes to determine whether or not a substance should be considered a carcinogen. An animal bioassay is a laboratory procedure in which scientists administer the test substance in one or more dose levels to one or more groups of animals and compare their cancer incidence to that of a control group that has not been exposed to the substance. Bioassays have several advantages over epidemiology:

> Laboratory testing on rodents avoids many of the pitfalls of epidemiological studies. Because experimental conditions and doses can be controlled, scientists can isolate the effect of a suspected carcinogen. In addition, because of the short lifespan of these animals, scientists can observe their response to a carcinogen within one or two years after exposure ([49],p.93).

Under the IRLC guidelines [28], a substance is considered as a potential human carcinogen once statistically significant quantities of tumors have been identified in experiments on at least one animal species [11,28]. However, there may be no direct evidence that the substance does indeed cause or promote cancer in humans.

The results of animal tests generally agree with human epidemiology. Of the 82 chemicals for which there is some epidemiological evidence of human carcinogenicity, all but arsenic have been shown to be carcinogenic in animals ([51],p.1201). However, because test populations cannot always be found for epidemiologic studies, it is not possible to determine how many of the chemicals found to be carcinogenic in animals are also carcinogenic in humans.

On the practical side, the use of animal testing is limited in some applications because of the time required (about three years) and the cost ($250,000 or more) ([52],p.589). Also, because of the limitations of space and trained personnel, the current capacity for animal carcinogenicity testing is about 300 chemicals per year ([51],p.1200), which is small compared to the 43,000 chemicals on the TSCA list of chemicals produced in or imported into the United States in the past four years [11]. However, many of these 43,000 chemicals will not be of interest for testing because human exposure to them is essentially negligible.

To overcome the cost and time requirements of animal testing, a number of short-term (in vitro) mutagenicity tests have been introduced. The most widely known of these tests is the Ames test, in which a mutant form of Salmonella bacteria is tested for mutations back to its normal form ([52],p.587). Most short-term tests are designed to detect damage to DNA, the theory being that this damage is a major cause of cancer and genetic birth defects.

The correlation between the results of short-term tests and animal tests is good but not perfect. Ames ([52],p.590) reported that of 300 chemicals reported as carcinogenic and noncarcinogenic in animals, about 90 percent (158 out of 176) of the carcinogens were found to be positive in the Ames test, while only about 12 percent (13 out of 108) of the noncarcinogens were positive in the Ames test.

In addition to the Ames test, there are many other short-term mutagenicity tests, including tests with cultured animal or human cells and improved versions of the drosophila (fruit fly) test for mutations after reproduction. The advantage of the tests with cultured cells is that the target cell may be more representative for actual cancer formation than a bacterial cell. On the other hand, a test with a small animal, even an insect, has the advantage of detecting possible carcinogenic metabolic products of a chemical. Additional short-term tests that will provide a more appropriate range of biochemical environment for the test cells are currently being developed. Many investigators favor the use of a battery of short-term tests, since no system is perfect and each system detects a few carcinogens that others do not ([52],p.591). However, with a battery of tests, the interpretation of a mixture of positive and negative results may be difficult.

Better understanding of the mechanisms for chemical carcinogenesis is urgently needed. The reasons a chemical will cause cancer in one species but not in another are rarely known. In the absence of such knowledge, regulators must assume that cancer in animals implies a potential for cancer in humans:

> Most carcinogens appear to undergo a chemical change before they produce their effect in the body....It appears that some chemicals cannot be activated to their carcinogenic form until some such metabolic process has taken place. Susceptibility to an agent may therefore depend on how it is metabolized. To date, little evidence suggests that the metabolism of agents to carcinogenic intermediates in animals is not similar to that in humans ([11],p.130).

Short-term tests and animal bioassays of suspect carcinogens may add to knowledge of the mechanism for chemical carcinogenesis. Research priorities for animal bioassays and cellular level tests should reflect this consideration in addition to the need to screen chemicals for regulatory decisions [53,54].

Use of Chemical Structure. Especially in the absence of test data on a specific substance, its chemical structure can often be used to estimate its potential toxicity. Even when test data are available, structural similarities with other known toxic chemicals may indicate that a chemical should be regarded as more hazardous than merited on the basis of the test data alone.

The use of structure to estimate toxicity is a variation of the use of "structure-activity relationships" (SAR), which have been used for years in the development of new drugs and pesticides. Basically, scientists start with a compound of known structure and activity and predict changes in biological activity with changes in the functional groups of atoms attached to specific sites. Structure-activity relationships can be used as a basis for categorization of chemicals in TSCA ([30],p.372). The IRLG has stated, "There is a moderately substantial base of empirical data that permits conclusions about carcinogenic potential on the basis of molecular structure" ([28],p.39870).

Dose Response Issues. In order to detect a toxic effect in a small number of animals in a test, typically a very large dose is required. The problem is first to extrapolate the response to lower doses in the test animal and then to translate that response to humans. One way of doing this is through mathematical models of response. Donniger has described some of the limitations of using such mathematical models:

> Limited to observations at unrealistically high doses in unrealistically low numbers, the scientist's recourse is to use mathematical models of dose response relationships to extrapolate from experimental results downward to the effects of low doses. However, like the theories on which they are based, the models yield widely divergent estimates of the risk associated with each low dose. The extent of the differences is astounding. For example, the major models differ by a factor of 100,000 on the size of the dose that creates a risk of one cancer in a million subjects. The models do provide credible outer limits for the risk associated with each dose, and they do permit the ranking of carcinogens in rough order of their potency. But they cannot provide the regulator with precise estimates of the risks of low doses ([55],p.592).

Even stronger criticism of the use of extrapolative predictions of dose-response relationships is found in a recent National Academy report on pesticide regulation [56], especially in Appendix A and in the references. From the literature, there appears to be no general consensus on the shape of dose response curves. The IRLG advocates the use of a linear model to give a conservative estimate of risks:

> The linear nonthreshold dose response model is most commonly used at the present time. Of the various models, it appears to have the soundest scientific basis and is less likely to understate risk than other plausible models ([28],p.39873).

Others, however, argue for the existence of thresholds below which no response occurs [57]. The more fundamental problem is, of course, the lack of knowledge of the basic causal mechanisms of cancer, including transport and metabolism in the body and potential detoxification of the chemical or repair of damaged cells. Apparently the only way to deal with these unknowns is to recognize that the uncertainties may extend over many orders of magnitude and to reflect the extent of such uncertainties in the conclusions to be drawn from analysis.

Exposure

Although it receives less attention in the literature, exposure is equally important as toxicity in determining risk:

> Characterization of risk must also take into account the nature of human exposure. Several questions must be asked: What are the sources of the chemical? Does the chemical encountered from each of these sources undergo any environmental alteration? By what routes and at what rates do humans come in contact with the chemical? How do these different routes and rates affect the risk? How many individuals are so exposed? Although considerable strides have been made in recent years in the identification of potential human carcinogens, little work has been done to define the nature and extent of actual human exposures to these chemicals ([29,p.173).

Another aspect in the calculation of risk is a description of the population exposed to a chemical and the differences in susceptibility in that population. As recommended by OSTP, "Characterization of risk should consider individual susceptibility" ([29],p.174). Furthermore, "Cancer susceptibility varies greatly among individual members of human populations due to genetic, racial, and ethnic factors; to environmental and dietary exposure; and to other modifiers" ([28],p.39875).

The Office of Science and Technology Policy report includes the following recommendation:

> Risk assessment should include consideration of the nature of human exposure to potential carcinogens. Appropriate research should be undertaken to determine sources, prevalence, and levels of exposure, as well as any environmental alteration, of the chemical under consideration ([29],p.16).

The IRLG report also strongly stresses the importance of information about exposure as part of the risk evaluation process ([28],pp.39873-39875).

In addition to routes or "pathways" of exposure through the environment, it is important to consider the means by which a chemical may enter the body and to investigate the chemical's pathways to the site of actual damage:

> The dose of an ultimate carcinogen at the site of action in the tissues or cells, which is measured at all times after its introduction ("target tissue dose") is ideally the dose that should be estimated and correlated with expected effects ([28],p.39874).

APPLICATION TO THE TOXIC SUBSTANCES CONTROL ACT

Risk-benefit analysis can be used for at least two purposes in the Toxic Substances Control Act. The first purpose is to assist in determining whether or not a chemical presents (or will present or may present) an unreasonable risk. Such a determination must be made before testing or control rules can be promulgated under the act. The second purpose of risk-benefit analysis is to help set priorities within the toxic substances office of EPA. Priority setting is related to the determination of unreasonable risk in that high priority should be given to chemicals that are likely to be found to present an unreasonable risk. It is also important because of the need to manage scarce testing and regulatory resources.

Unreasonable Risk

The determination of unreasonable risk is the key element in the implementation of TSCA. In order to regulate a chemical under Section 6 of the Act, the EPA Administrator must find that a chemical "presents or will present" an unreasonable risk. And, in order to require testing of an existing chemical under Section 4 or to regulate a new chemical pending the development of information under Section 5, the administrator must find either that the chemical "may present" an unreasonable risk or that the chemical may enter the environment in substantial quantities or result in significant human exposure. Thus, a distinction is drawn between the finding of "presents or will present" an unreasonable risk and the less demanding finding of "may present" an unreasonable risk.

In any case, the term unreasonable risk is purposely not defined in the Act. According to the House Report, the term was not defined because the determination of unreasonable risk is not a factual question but a complex exercise of judgment that involves

> ...balancing the probability that harm will occur and the magnitude and severity of that harm against the effect of a proposed regulatory action on the availability to society of the benefits of the substance of mixture, taking into account the availability of substitutes for the substance or mixture which do not require regulation, and other adverse effects which such proposed action may have on society ([58],p.14).

The determination of unreasonable risk is thus a judgment involving the "balancing" of risks and benefits where risk is defined as the probability of harm together with the magnitude of the potential harm and benefit is defined as the economic usefulness of the substance. An important point in this statement is the use of the concept of probabililty, which indicates that a chemical may be found to present an unreasonable risk even if the exact toxicity or exposure of a chemical is uncertain.

Because of the difficulties in assessing toxicity and exposure, similar difficulties in assessing the economic effects of regulation, and the difficulties in assigning values to potential outcomes, the determination of unreasonable risk is extremely complex. However, EPA is required by TSCA to make such determinations, usually within certain mandated time limits. For example, after receiving a premanufacture notice for a new chemical, EPA has at most 135 days to determine whether the chemical should be allowed to be manufactured or whether more information needs to be submitted. Similarly, EPA has one year to act on chemicals that have been identified by the Interagency Testing Committee (ITC) to be of high priority. In either case, EPA always has the alternative of doing nothing, i.e., taking no rule-making action. However, this choice should be made consciously and not by default. To help prevent decisions by default, TSCA often requires EPA to publish the reasons for not taking regulatory actions.

As yet there is no source in the literature claiming to provide a definitive method of determining unreasonable risk. However, a number of authors have suggested elements of such a determination. Lowrance [6] draws a clear distinction between matters of empirical fact and matters of personal or social value judgment. The determination of unreasonable risk (insufficient safety) is thus a combination of empirical findings and value judgments.

Another important aspect of unreasonable risk arises from the uncertainties in the risks and benefits of a chemical. Because of the uncertainties, it is possible to make "regulatory errors" in the sense that a different regulatory option may have been preferable if the true toxicity, exposure, and benefits of a substance were known. As described by Page, "The essence of the balancing process is the willingness to accept some false positives as the unavoidable means of controlling false negatives" ([47],p.3). By false positives, Page means restricting a substance that is in fact safe for humans; regulation is not necessary and the benefits are lost. By false negatives, he means failing to control a chemical that turns out to be damaging to human health or the environment to an extent that is not justified by benefits from the chemical. Thus, a necessary result of the balancing process is the acceptance that errors of both types are unavoidable. A partial solution to this problem may be to allow a certain flexibility in the regulatory decision-making process so that decisions can be changed if new information is discovered, indicating a chemical restricted by regulation is nontoxic (false positive) or an unrestricted chemical is inflicting unacceptable damage (false negative).

A key issue that has not received sufficient attention to date is the formulation of decision criteria for making unreasonable risk determinations. Currently, EPA has elaborate procedures for analyzing information on chemicals but does not have explicit criteria for the decision points in the process. As a result, it is necessary to consider each chemical on a case-by-case basis. It is therefore difficult to check for consistency of decisions, and the decision makers may be subject to political influence and pressures that could be more easily resisted with explicit criteria for decision making.

Two attempts at formulating decision criteria were posed by the Conservation Foundation and by Page. The Conservation Foundation recommends a procedure in which the effects of regulatory options are quantified in a variety of units such as lost lives, lost jobs, and dollar costs. The estimated effects are then aggregated by "subjectively established weighting numbers" to avoid translating all factors into dollars and to emphasize the fact that the weights are subjective ([7],p.15). Page recommends use of quantitative values and probabilities to describe the uncertain effects of regulation. The net benefits of a regulation are then calculated as an expected value ([47],p.3).

Priority Setting

Both regulatory staff and facilities for chemical testing are resources in short supply within the Office of Pesticides and Toxic Substances (OPTS), and these resource limitations affect the rate at which TSCA can be implemented. Priority setting is the means of managing these scarce resources. Suggested principles for priority setting are described in the recent Office of Science and Technology Policy report:

> For testing, highest priority should be given to chemicals for which preliminary analysis suggests that regulation may be indicated but for which existing data are too uncertain to justify immediate action. These chemicals would generally include ones that have a high potential for carcinogenicity (based upon structural similarity to known carcinogens or the results of short-term in vitro tests) but have had only minimal prior testing, ones that offer substantial consumer benefits, and ones that do not have readily available means of controls ([29],p.174).

Thus, priority setting involves a preliminary risk-benefit analysis, presumably of less detail than that required for regulatory action but in enough detail to indicate the type of regulatory action that may result and the approximate value of such regulation. One disputable point, however, is the assumed inability to regulate if data are uncertain. Given the time constraints for TSCA, it may be necessary to make a regulatory decision before testing to reduce uncertainty can be conducted. Furthermore, because it is impossible to remove all uncertainties, presence of uncertainty cannot prevent decision making.

To aid in rapidly setting priorities, Slesin and Sadler advocate the use of categories of substances:

> The inclusion of a chemical in a category of suspected toxic substances should raise sufficient "concern" over its safety to indicate that the substance "may present" an unreasonable risk, and therefore, categorization may aid in the establishment of testing priorities ([30],p.390).

Such categorization could help in assessing the probability of harm for a substance.

Presently, priorities for testing are set by the ITC, which was established under TSCA. The ITC has developed a priority-setting methodology in which chemicals are scored on the basis of exposure and toxicity [59]. Similar methodology could also be used to set regulatory priorities. The methodology does allow a ranking of chemicals according to score, but it has been criticized for ignoring the possible regulatory actions that may be required as well as for ignoring economics:

> One difficulty in using the ITC methodology to select existing chemicals for possible regulatory action is that it considers the risk of the chemicals in toto. Aggregating all uses, exposures, and effects into a single final rating, the method fails to distinguish among different uses of the chemical, its use in different geographical areas, or the potential impact of a wide variety of regulatory options short of banning. Thus, if this analysis shows that a chemical presents a risk, the implicit assumption is that the only regulatory option available under TSCA is a total ban. While this approach is the most economical one in terms of resources expended to collect information, it may result in overlooking situations where regulatory action--controlling certain uses or production volume, for instance--could have the greatest payoff, reducing the risk from a chemical to a level considered reasonable rather than banning it entirely ([7],p.3).

The ITC scoring system can also be criticized as being highly subjective and potentially inconsistent. The numbers have little meaning once they are aggregated, and the uncertainty is not quantified in a way that can be easily communicated to those who have not participated in the scoring process.

One possible alternative to the ITC methodology is the ranking system developed for EPA by SRI [60]. The so-called objective component of this system does provide an outline for a simple analysis of the risks of a chemical. However, this system also ignores economic effects and uncertainty.

Another alternative may be a simplified decision analysis framework that utilizes a highly aggregated model of exposure and toxicity as well as a simple market model. Using the structure, a few regulatory options could be considered and uncertainties could be explicitly incorporated. This approach may have promise but is currently undeveloped.

CONCLUSIONS

Risk-benefit analysis methodologies, particularly decision analysis, appear applicable to the regulation of toxic substances, but examples of such application are rare. The proper role of analysis is agreed to be an aid to responsible decision makers, and the objective of analysis should be to organize information and clearly present all assumptions and value judgments. The application of risk-benefit analysis to chemical hazards is difficult because of the general lack of understanding of the toxicity of low levels of exposure and the pathways of exposure. However, because regulatory decisions must be made even in the face of uncertainty, it makes sense to use a method of analysis that deals with the uncertainty in a logical way rather than assert that uncertainty makes analysis impossible or useless. Progress has been made in developing methodologies to deal with the specific problems of implementing TSCA, namely, methodologies to determine unreasonable risk and to set priorities. However, much more development, refinement, and experience in applications appear to be needed before the methodology can be used as an operational framework to assist EPA decision making in determination of unreasonable risk and in setting priorities for allocating testing and regulatory resources.

Section 3

DECISION ANALYSIS METHODOLOGY FOR UNREASONABLE RISK DETERMINATION

OVERVIEW

Under Section 6 of the Toxic Substances Control Act (TSCA), the EPA must select from a wide range of regulatory alternatives if there is a "reasonable basis to conclude" that a substance "presents or will present an unreasonable risk" to health or the environment. The determination of unreasonable risk is also required by several other sections of the Act. In this section, we will discuss a decision analysis methodology that can be used to help determine if an unreasonable risk exists or will exist. Of perhaps greater benefit, use of the methodology will provide information and insights that can help guide the EPA in the selection of regulatory alternatives.

NATURE OF THE TOXIC SUBSTANCES PROBLEM

The term unreasonable risk appears over thirty times in TSCA, yet it is not defined in the Act. It seems clear that Congress felt there was no single, objective definition of unreasonable risk; as stated in the House Report [61], the determination of unreasonable risk is a complex process of information gathering, analysis, and judgment which involves

> ...balancing the probability that harm will occur and the magnitude and severity of that harm against the effect of proposed regulatory action on the availability to society of the benefits of the substance or mixture, taking into account the availability of substitutes for the substance or mixture which do not require regulation, and other adverse effects which such proposed action may have on society.

Inherent in the statement are two concepts central to a determination of unreasonable risk: the balancing of risks and benefits and the explicit consideration of uncertainty in the risks and benefits, the uncertainty being described in terms of the probability that harm (and other uncertain outcomes) will occur.

Before an EPA decision maker can exercise judgment in the balancing of risks and benefits, he or she must have a good understanding of what the important risks and benefits are or may be. Gaining this understanding presents a challenging problem: numerous issues are involved, interacting in a complex manner, and information is always limited. Even for chemicals produced in large volumes for many years, crucial information on toxicity, uses of the chemical, and dispersion of the chemical in the environment may be unavailable.

Factors that must be considered when evaluating a substance for its potential to cause harm include the techniques of its production, use, and disposal, pathways of exposure to both humans and the environment, and the biological responses of humans and other organisms. Chemicals or mixtures may be acutely or chronically toxic, carcinogenic, mutagenic, or teratogenic. The dose required to produce the adverse effect varies widely among toxic substances, and for most substances the dose response relationship is highly uncertain. Some effects may be due to synergistic interactions between several substances or metabolic transformation. Harmful effects may appear only after a period of time has passed, due to bioaccumulation or latency in the effects, or both.

Even when information is available on a possible hazard, it may be ambiguous or inconclusive. If a large human population is exposed to low concentrations of a substance, and the same substance appears to increase significantly the number of tumors when administered to rodents in large doses, what is the extent of the danger? There is uncertainty in extrapolating from high to low doses, from animals to humans, and perhaps from short- to long-term exposure. The mechanisms of uptake and metabolic transformation may be poorly understood. Is the substance itself a carcinogen? Is some metabolic byproduct of the substance a carcinogen? Or is the substance a cocarcinogen whose effect depends on the presence of some other compound? These are but a small sample of the questions and uncertainties likely to be raised when assessing the potential for risk to human health. The processes through which a substance may present a risk to the environment--whether to individual species or to an entire ecosystem--are likely to be similarly complex and uncertain.

It is often believed that the economic benefits of a substance (or the economic costs of regulation) are better understood or easier to calculate than are the risks. Unfortunately, this may not always be the case. An existing substance may be involved in a complex network of economic interactions: competing in several market areas, being used as an end product or a factor of production in diverse ways, and generating a demand for a set of feedstocks and other input factors. There may be uncertainty in the benefits of use, as with certain pesticides where resistant strains of the pest have developed in some geographic areas but not in others. The availability of substitutes or the opportunities and costs of developing substitutes can be a critical issue and one fraught with uncertainties. While vast quantities of data on production and use may be available, such data may be of little use in assessing the changes that may result from regulatory action.

In the case of a new substance or significant new use, the problem can be even more difficult. The markets in which the substance will compete may not all be clearly identified, nor will the materials that may be displaced. Processes for large-scale production are likely to be unproven, leading to uncertainty in costs, prices, and byproducts. Estimating the economic benefits of a new substance may be every bit as challenging as assessing its potential risk.

An important characteristic of the problem of determining unreasonable risk is that both risks and benefits may be received in different proportions by many diverse groups in our society. This may result simply from the nature of production and use of a substance: production workers and those who use a product are likely to receive greater exposure than will the general public. Or, it may be for biological reasons. For example, certain groups, such as the aged, may be more susceptible to a particular toxic reaction. In terms of economic effects, parties that may feel the impact of a regulatory action (or of no action) include the producers of a substance, suppliers of existing or potential substitutes or complements, feedstock suppliers, and consumers of the end product. Even within the production sector, the effects may vary over diverse groups: workers whose jobs may be eliminated (or created), shareholders in a firm, or members of a surrounding community. Assessing the impacts on all concerned parties is part of what makes the determination of unreasonable risk such a difficult problem, and it must be addressed within any analytical methodology.

We have described just a few of the issues, complexities, and uncertainties that make the determination of unreasonable risk--and the choice of an appropriate regulatory alternative--an extraordinarily challenging problem. In the remainder of this section we will discuss a decision analysis methodology that can provide a first step towards meeting the challenge. We will begin by discussing the purpose of such a methodology, what it can be expected to provide, and what it will not provide. We will then present the generic structure of the methodology, and finally outline the steps of the analysis process.

PURPOSE OF A DECISION ANALYSIS METHODOLOGY

At a concrete level, the purpose of a decision analysis methodology is to provide consistent quantitative estimates of the harm that may result from the use of a substance as well as the benefits of such use, of the economic and other costs of regulatory alternatives, and of the degree of uncertainty in both risks and benefits. A good analysis will clearly identify the groups or individuals who will receive the benefits and bear the risks, the timing of various outcomes, and the nature of each impact. Summarizing the factual results of an analysis may, however, miss its broader purposes: to provide a way of integrating the diverse issues and information, to provide a framework for communication, and to improve an understanding of the critical issues, uncertainties, and impacts.

The problem of determining whether a substance presents an unreasonable risk involves a vast number of factors. One way in which a decision analysis methodology can help is by providing a framework with which to integrate the important factors of the problem. A central tool in this regard is an explicit model representing the interactions between the various aspects of the problem. The model allows the economic, physical, biological, and other factors to be integrated into a comprehensive analysis. It provides a framework within which the knowledge and information of experts from diverse fields can be pulled together in a consistent manner. Beyond the use of an explicit model, the decision analysis approach allows uncertainties--which may be critical in unreasonable risk decisions--to be included as an integral part of an analysis. This helps make the impact of the uncertainties clear and focuses efforts on those uncertainties of the greatest importance.

As just noted, a model plays a key role in integrating information from diverse sources. The decision analysis methodology in general and an integrating model in particular also facilitate communication among the parties concerned with an unreasonable risk determination. The model requires assumptions about both processes and data to be made explicit; it also allows the implications of alternative assumptions to be tested and compared. The decision analysis approach can help focus debate on the key issues--the ones that are crucial to a particular unreasonable risk regulatory decision. By making assumptions and data explicit, it can clarify where agreement exists and where it does not.

The need for clear and concise communication is a primary reason for quantitative analysis. We view numbers as a language, that is, as a tool for communication. The quantitative results of an analysis should be much more than a single "bottom-line" number: they should include ranges, sensitivities, and disaggregation of risks and benefits by type of outcome and impacted group. Again, this approach will help make clear the critical issues and uncertainties.

A quantitative decision analysis methodology should not be expected to provide an objective, "scientific" mechanism to generate an "answer" for an unreasonable risk determination. Rather, it should help the decision makers and other interested parties understand the problem better. The methodology should help to focus attention on what is most important, on the issues that are most critical to the regulatory decision. While using available information to the fullest extent possible, the decision analysis methodology will provide guidance as to the need for more information and will enable new information to be factored in a consistent manner. The analysis will not make the decision regarding unreasonable risk; it will give the decision makers the information and insights that should provide a firm basis for the judgment required to make the regulatory decision.

OUTLINE OF THE METHODOLOGY

The decision analysis methodology consists of a conceptual framework within which to define a specific unreasonable risk decision, a generic structural model that is detailed for a specific decision, and a process or series of steps for carrying out the analysis. In this section we will discuss the general structure of an unreasonable risk decision analysis, introduce some key methodological concepts, and summarize the analysis process.

To illustrate the methodology, we will develop a sequence of examples around an unreasonable risk decision regarding a hypothetical substance, the chemical XYZ. While being simplified and representing only a small portion of a complete analysis, the examples will be more specific and occasionally more technical than the body of the section. To avoid confusion between the necessarily simplified assumptions of the illustrative example and the more general description of the methodology, all discussions of the examples will be single spaced and indented.

> Our hypothetical substance XYZ is a resin used in the production of a family of industrial adhesives. These adhesives compete in the marketplace with other adhesive compounds, and also with other fastener technologies. A new adhesive containing XYZ is being considered for marketing as a consumer product; it would compete with existing household adhesives.
>
> XYZ can have serious acute toxic effects when ingested in greater than milligram quantities. Particularly sensitive individuals may have an acute reaction from surface exposure. The risks of such acute effects from occupational exposure are relatively small when common industrial safety procedures are used.

> Consumer users of the new adhesive may be exposed to XYZ through three possible pathways: direct skin contact with the uncured adhesive, fumes from the uncured adhesive, and leaching from cured adhesive when it has been used to repair eating utensils. It is believed that none of these pathways will lead to significant acute toxic effects.
>
> Structure-activity relationships indicate that XYZ is a possible carcinogen. Epidemiological studies carried out on employees of plants producing and using XYZ have provided no clear indication of carcinogenicity, but the number of individuals involved was small. Furthermore, XYZ has been in regular industrial use for only about ten years; any adverse effects may not appear for another ten years.

Defining the Decision

The first step in carrying out a decision analysis is to carefully define the decision problem. For a particular chemical substance or class of substances we must characterize the dimensions of the problem of determining whether or not an unreasonable risk exists, and, if so, what regulatory actions should be taken. By dimensions we mean what choices the EPA must make, the alternatives available, the outcomes of interest, and the information on which the analysis and decision must be based. One way of visualizing how these factors fit together is illustrated in Figure 3-1; the central role of an integrating model is indicated as well. Each specific decision will have only a certain set of alternatives available, a unique set of outcomes that are felt to be most important, and a unique combination of available and unavailable information.

Outcomes and Decision Criteria. To arrive at a more precise definition of the unreasonable risk decision we must ask what we want. Then we should be able to identify the important things we would like to know, after a decision is made, to see whether things turned out well or badly. The measures by which we judge how well things turned out we choose to call outcomes. The outcomes of any toxic substance regulatory decision will generally fall into one of three categories: human health, environmental impacts, and economic effects.

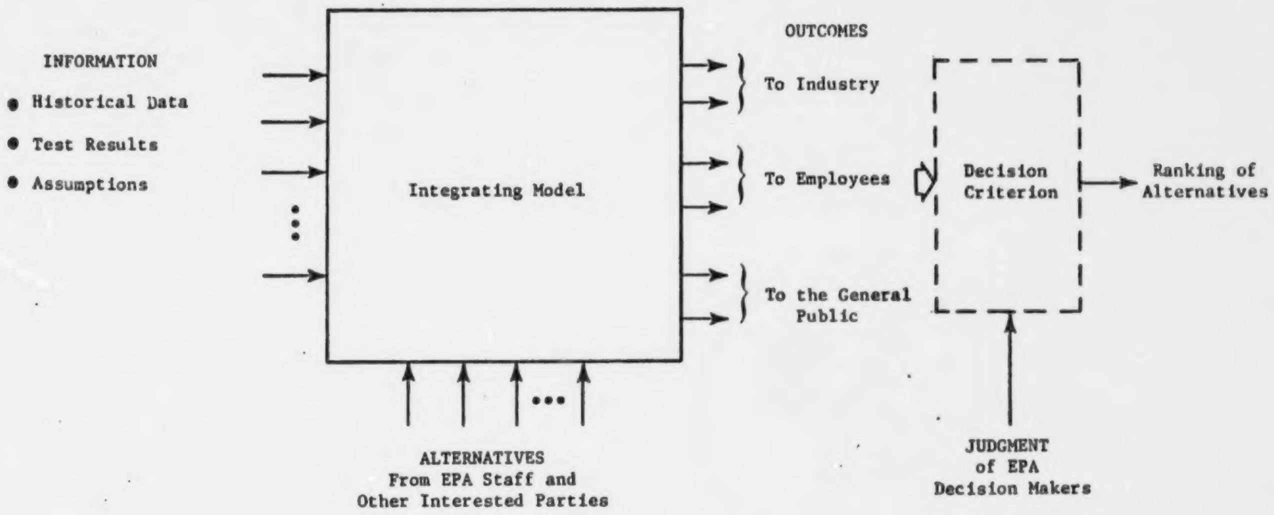

INFORMATION
Historical Data
Test Results
Assumptions
Integrating Model
ALTERNATIVES
From EPA Staff and
Other Interested Parties
OUTCOMES
To Industry
To Employees
To the General Public
Decision Criterion
Ranking of Alternatives
JUDGMENT
of EPA
Decision Makers

Figure 3-1. Components of a Decision

A given toxic substance may cause one or more of a wide variety of health effects. What we would like to know is how many people will be affected and to what degree. As the uncertainty is likely to be considerable when estimating health effects, what we might expect from an analysis is a probability distribution on the number of people incurring each health effect. An EPA decision maker will need to know more than simply a raw number (or range) of people affected; we can provide a more complete definition of each health impact by describing it (qualitatively or quantitatively, as appropriate) along each of the following five dimensions:

1. The nature of an effect: this could range from a mild annoyance (e.g., a simple allergy) to severe distress (a serious illness) to death.
2. The timing of an effect: how soon after exposure does it occur? This will range from immediately, as in the case of acute toxicity, to perhaps ten or twenty years (e.g., with cancer).
3. The duration of an effect: how long does the effect last? This might be for a very short period (e.g., an allergy only upon exposure) or indefinitely (as with a chronic respiratory illness).
4. The recipient of an effect: the users of the substance (e.g., consumers of a final good); employees in manufacturing, processing, or distribution; the general public; or perhaps special groups, such as children, the elderly, or those exposed to some other substance.
5. The number who incur the effect, described in terms of a best estimate and probabilities on the range of possible outcomes.

When analyzing a specific substance to determine if it presents an unreasonable risk, there will usually be a small number of health effect definitions: perhaps one type of disease that affects several distinct groups in society, or several different diseases affecting the general public, or some other combination.

The environmental impacts attributable to chemical substances can appear in a vast number of forms. They can range from a short-term impact on a single species to a permanent major modification of an entire ecosystem. While environmental impacts are in general more difficult to categorize than are human health effects, for a specific regulatory decision there is likely to be a small set of critical environmental impacts. Each might be characterized along the following dimensions:

1. The severity of the impact on an individual organism.
2. The number of species affected.
3. The duration of the environmental harm.
4. The geographic extent of the effect.
5. The reversibility of the effect, as for example, elimination of an endangered species as compared to a temporary reduction in species population.

We now return to the hypothetical example.

> To define outcomes that reflect the health effects of the production and use of XYZ, we refer back to the general discussion of its use and characteristics. Two potential health effects were noted: illness resulting from an acute toxic reaction and cancer. For the purposes of this simplified example we will assume that the acute effects are not a central issue. Groups that might be affected include employees of firms that manufacture XYZ, employees of firms that use products containing the substance, and consumers who might use the potential new product. Thus, the health effects outcomes can be summarized as
>
> o Number of cases of cancer associated with exposure to XYZ where the effect may be incurred by
>
> --employees of XYZ production plants
>
> --employees of firms using products containing XYZ
>
> --consumers using an adhesive containing XYZ
>
> We now have three distinct measures of outcomes. Each can occur now or at any future point. Thus, the outcomes need to be defined along the time dimension: the number of cancers detected in 1980, 1985, 1990, and so on.
>
> As the analysis of XYZ evolves we may discover that additional outcomes are necessary or that one previously defined is no longer an issue. We may, for example, choose to disaggregate the cancer occurrences by age group, sex, or both. This illustrates the iterative nature of the decision analysis process, making successive improvements and refinements as one gains understanding of the problem and its key attributes.

Economic impacts can be incurred by a variety of parties, the most important of whom include manufacturers of a chemical or mixture, those who use it as an end product or factor of production, current or potential suppliers of substitute substances, and employees of the firms involved. Which parties receive costs or benefits depends both on the characteristics of the industrial processes and economic markets, and on the nature of any regulatory actions. Consumers might bear costs due to higher product prices, lower quantities, or a poorer selection of products. Suppliers can incur costs because of lower production quantities, increased production costs, or unrecovered R&D expenses. Whatever the specific nature of the economic impacts of a regulatory action, the impacts will generally occur in one or more of three forms: net dollar costs or benefits, changes in employment, and effects on innovation. The first two can be quantified, while the third is a more qualitative measure. Thus, the economic outcomes of a toxic substance regulatory decision can be summarized by providing estimates of

1. The net dollar benefits (or costs) received by each industrial sector involved to a significant degree (disaggregated geographically when necessary).
2. The net change in employment (again, it may be important to distinguish by geographic region).
3. Changes in price, quantity, and quality of products available to consumers.
4. Impacts on innovation.

These effects may occur immediately after a regulatory action is taken, or they may appear gradually. The manner in which the economic outcomes change over time may be important in an unreasonable risk decision analysis.

> There exist competing materials for both current and proposed uses of XYZ. Thus, regulatory action with respect to XYZ is unlikely to eliminate any final goods available to consumers. There will be both production cost and price effects, which may occur at several points in the economy. While many of the effects propagate from intermediate producers to final producers to consumers, we must take care to avoid double counting.

For the purposes of the example, we will assume that the economic effects outcomes are as follows:

- Net economic benefits to
    - --firms that produce XYZ
    - --firms that use XYZ
- Net change in consumers surplus [62]

As with health effects, the economic outcomes must be estimated for a number of points in time. We will assume that disaggregation by location (e.g., of impacted firms) is judged to be unnecessary.

The preceding few paragraphs have outlined outcomes that are likely to be important in judging whether a substance presents an unreasonable risk. Presenting this information to the EPA decision makers and other interested parties in the form of qualitative descriptions, quantitative estimates, and probability ranges does not, however, complete the decision analysis process. It is clear that it will be necessary to make tradeoffs when balancing the risks of harm to humans and the environment with the costs of regulation. Ultimately, these tradeoffs will be reflected in the judgment of the decision makers. We believe that it would provide useful insights to develop quantitative tradeoffs that could be used to estimate the overall impact of each alternative.

As with other aspects of the decision analysis methodology, the purpose of making these tradeoffs explicit is not to obscure the numerous factors involved (to reiterate: the full set of disaggregated outcomes should be made available to all interested parties), but rather to aid in understanding which factors are most important to the decision. Primary uses of an explicit set of tradeoffs will be to facilitate sensitivity analysis and value of information calculations, both of which will be discussed below. Alternative tradeoff values can be tried to see if varying the tradeoffs changes the ranking of the regulatory options. This can help focus debate on the outcomes and tradeoffs that are most crucial to the decision, while providing a basis for agreement (at least, an agreement that they are less critical) on other outcomes:

56

> To carry out sensitivity analysis and to estimate the value of obtaining more information, it is necessary to specify a tentative set of tradeoff values between the outcomes. Both economic outcomes are in dollar values, while the remaining outcome is measured in the number of cases of cancer. It does not matter in principle which measure is "traded off" into the other; for simplicity, we will use dollars as the "net" outcome.
>
> As a starting point we shall specify the tradeoff as one statistical case of cancer is equivalent to ten million dollars. In a complete analysis we would test the implications of a wide range of tradeoff values from, for example, one hundred thousand to one hundred million dollars. The tradeoffs need not be constant; they might be a function of the number of cases of cancer, or economic benefits, or both.
>
> Note that for this simplified example we are simply adding the two economic (dollar) outcomes, the net benefits to industry, and the net benefits to consumers. If distributional issues were felt to be significant, the costs (or benefits) incurred by consumers need not be considered equivalent to those incurred by industry.

Decisions and Alternatives. The decisions that the EPA must make under TSCA can be summarized as determining whether or not unreasonable risks exist or may exist. We find it useful to define the decision as being the choice of an appropriate regulatory action, where no action is always a possibility. An explicit assumption is that no further action will be taken if it is judged that an unreasonable risk does not exist and that some action will be taken if such a risk does (or will) exist. Thus, in defining the decision it is useful to define in greater detail the regulatory alternatives, keeping in mind that "do nothing" is always an alternative.

For the purposes of structuring a generic decision analysis methodology, it is useful to think of an alternative as being defined along four dimensions:

1. Type of action (record keeping, label warnings, limit, prohibit)
2. Economic stage (manufacturing, processing, distribution, use, disposal)
3. Type of use (all uses, a set of uses, a single specific use)
4. Geographic extent (everywhere, in specific areas)

For example, one complete alternative might be to limit a substance's use to a particular set of applications and prohibit the substance's manufacture for all other purposes. Another alternative could be to prohibit use in certain ecologically sensitive geographic areas, while requiring warning labels on distribution of the substance in the rest of the country. Not all alternatives will be available for every chemical substance, and many alternatives will clearly be inappropriate due to the nature of the potential harm or the characteristics of the economic sector. However, it should be possible to define any alternative reasonably well using the four attributes just listed.

> As an analysis evolves, the alternatives under consideration will evolve as well, with new alternatives emerging as the problem becomes better structured and better understood. While it is not necessary to begin with every alternative specified in complete detail, it is essential to start out with a set of alternatives that "span" the full range of possible actions. The following is an initial set of alternatives with respect to the substance XYZ:
>
> 1. Take no action, e.g., permit all uses.
> 2. Prohibit the new consumer use, while allowing industrial uses to continue with appropriate safeguards.
> 3. Phase out existing industrial uses over a 10-year period and prohibit any new uses.

It is clear that an action taken at one stage (e.g., to limit manufacturing of a substance) will affect the other stages (e.g., its distribution and use). The purpose of classifying the alternatives as described is to enable us to identify clearly at what point(s) the regulatory action has an impact on the physical, biological, and economic systems. This will be of importance when we begin to think about modeling the effects of a regulatory action.

Information and Uncertainty

One of the key characteristics of the determination of unreasonable risk that makes it a difficult problem is that we do not really know everything about each aspect of the problem, and in many cases we know very little. In other words, our information is always incomplete and usually very limited. The result of the lack of information is uncertainty: we do not know precisely how much of a substance is produced, or how much escapes to the environment, or what all the pathways of exposure are, or what the biological processes are that lead to an illness. As the examples indicate, this uncertainty is often in what we might call "data" or "parameters;" something in which the precise answer, if it could be given, would be in the form of a number (or set of numbers). Sometimes the uncertainty has to do with the nature of the physical or biological relationships: Is the dose response relationship for a particular substance linear, or a probit-log, or in some other form? In such cases, we are uncertain about the underlying processes as well as numeric values.

While the uncertainty is often very great, it is also important to recognize that only rarely are we totally without information. We usually have some idea of the range for a variable, even if we do not know its exact value. The fraction of employees involved in a manufacturing process who are exposed to a certain substance may be twenty percent, or it may be thirty percent, but we are fairly certain that it is greater than one percent and less than fifty percent. In other words, we do know something. A fundamental concept of decision analysis is that decisions must be made even when complete information is not available, that is, under uncertainty. There will rarely be enough scientific data to resolve all uncertainty. In order to make good decisions we should make the best possible use of all available information, however limited that may be.

Representing Uncertainty. A cornerstone of the decision analysis approach is the idea that uncertainty reflects an individual's state of information about some quantity or event. The information he or she has includes subjective judgment as well as scientific data. In the decision analysis process this state of information--and, conversely, state of uncertainty--is represented by probability assignments that specify explicitly what the chances are of each of the possible data values (or structural relationships) occurring. The probability assignments are elicited from the decision maker or others knowledgeable in the subject using a process called probability encoding [31]. The encoding procedure is a structured interview designed to eliminate biases. The probability assignments thus specified reflect the full information--both quantitative and qualitative--that is available to the EPA and others involved in the analysis at the time the decision is made.

> Probabilities are key parts of the language we use to deal with uncertainty. They describe our state of information about the likelihood of an event. There are several ways of representing probabilities, depending on the nature of an event. The simplest case is when a discrete event either will or will not occur (or when, equivalently, a statement is or is not true). For example, suppose that our best judgment indicates a 10 percent chance that XYZ is a human carcinogen; we could write
>
> $$P(\text{XYZ a carcinogen}) = 0.1$$
> $$P(\text{XYZ not a carcinogen}) = 0.9$$
>
> Even when uncertainty is not an issue, we often wish to qualify statements such as "B will occur if A occurs." The analog in the language of uncertainty is the conditional probability. As an example, suppose we believe there is an 85 percent chance that an Ames test will be positive if XYZ is a carcinogen and a 20 percent chance for a positive result if XYZ is not a carcinogen. This can be written as
>
> $$P(\text{test positive} \mid \text{XYZ carcinogen}) = 0.85$$
> $$P(\text{test positive} \mid \text{XYZ not carcinogen}) = 0.20$$
>
> Probabilities must always sum to one (including probabilities on conditioned events), so we also could note that
>
> $$P(\text{test negative} \mid \text{XYZ carcinogen}) = 0.15$$
> $$P(\text{test negative} \mid \text{XYZ not carcinogen}) = 0.80$$
>
> Probabilities used to represent the likelihood of various values for a variable are only a bit more complicated. Figure 3-2a shows a probability density function, giving the relative likelihood of each value for the number of tons of XYZ used in consumer products in 1985. (Such a function is always normalized so that the area under the curve is one.) In Figure 3-2b, we have an equivalent but perhaps more intuitive representation: a cumulative probability distribution. Each point on the curve gives the probability that the amount of XYZ in adhesives used by consumers is less than or equal to the value on the horizontal axis. For example, there is a 70 percent chance that the number of tons/year of XYZ used by

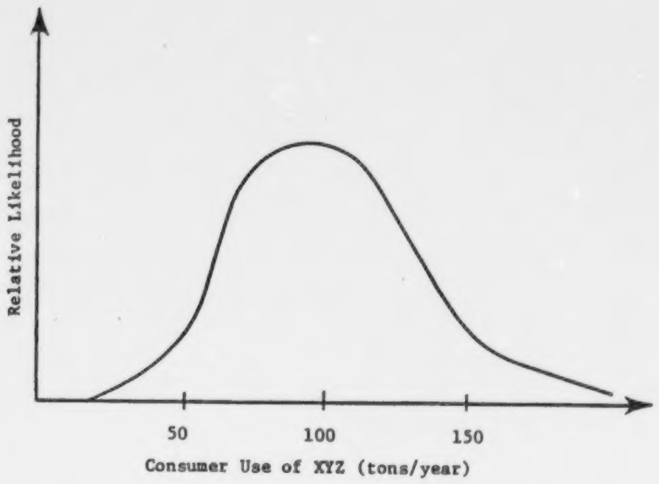


Figure 3-2a. Example Probability Density Function

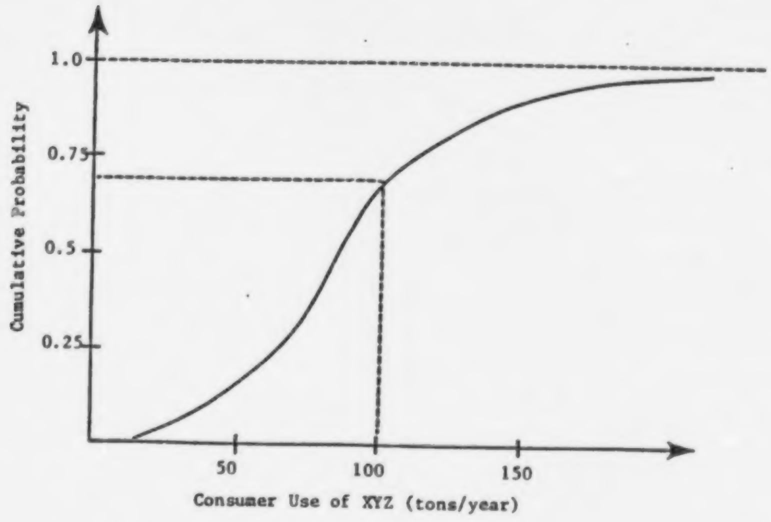


Figure 3-2b. Example Cumulative Probability Distribution

> consumers is less than or equal to 100. It is often more convenient for computation to use a discrete probability mass function rather than a continuous distribution. An example is shown as Figure 3-3a.
>
> A convenient way to represent the probabilistic relationships between the decisions and key uncertainties is with a decision tree. Such a tree has two kinds of nodes: decisions, represented by boxes, and uncertainties, represented by circles. A probability mass function translates directly to an uncertainty node, as shown in Figure 3-3b.
>
> A simplified generic decision tree for unreasonable risk decisions is shown as Figure 3-4. Rather than detailing all decision alternatives or uncertain events, only their ranges are indicated. In this tree the decision and uncertainty, or chance, nodes are not connected. This convention is a shorthand representation of the full tree where each node is connected to all branches of the preceding node.
>
> Each path through the tree represents a scenario, a description of a possible sequence of events. The product of the probabilities along the branches of the uncertainty nodes gives the likelihood of the scenario's occurring. A probabilistic scenario defines the values of all critical uncertainties. These values, one for each uncertainty node, can then be used together with other data to calculate the values associated with the scenario of the important outcomes.

An important benefit of this approach is that it is quite straightforward to factor new information into the analysis as it becomes available. Simple rules from probability theory are used to "update" the probability assignments based on the new information [12,15]. The process is intuitively reasonable: if the new information tends to confirm the previous "best guess," the range of uncertainty will decrease; if we are "surprised" by what we learn, the range of uncertainty can increase. Either way, the implications of the new information on our estimates of the outcomes can quickly be evaluated, which may in turn either confirm or modify our judgment regarding the best regulatory alternative.

> Suppose we have a bioassay for carcinogenicity that has an 85 percent chance of being positive if the substance tested is a carcinogen and a 20 percent chance of indicating positive if the substance is not a carcinogen. We can summarize this as

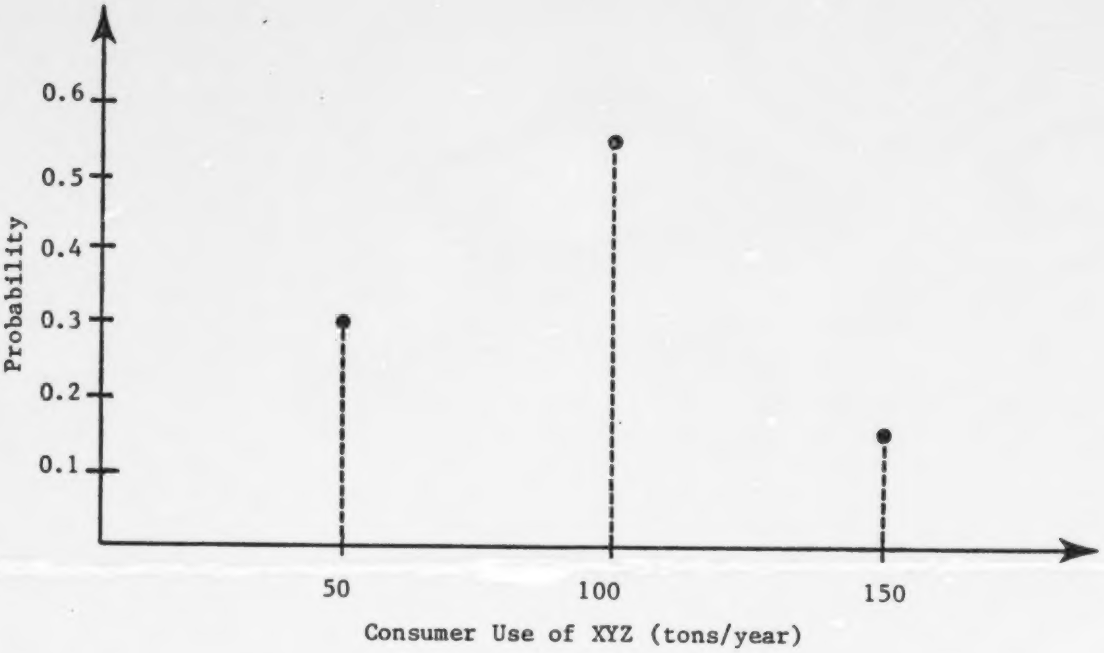


Figure 3-3a. Example Probability Mass Function

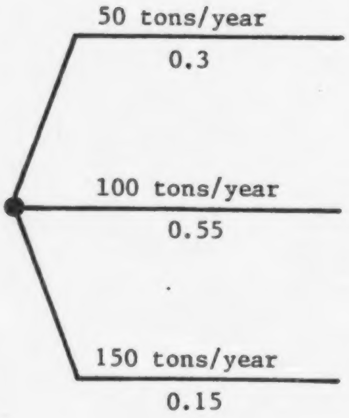

50 tons/year
0.3
100 tons/year
0.55
150 tons/year
0.15

Figure 3-3b. Example Decision Tree Probability Node

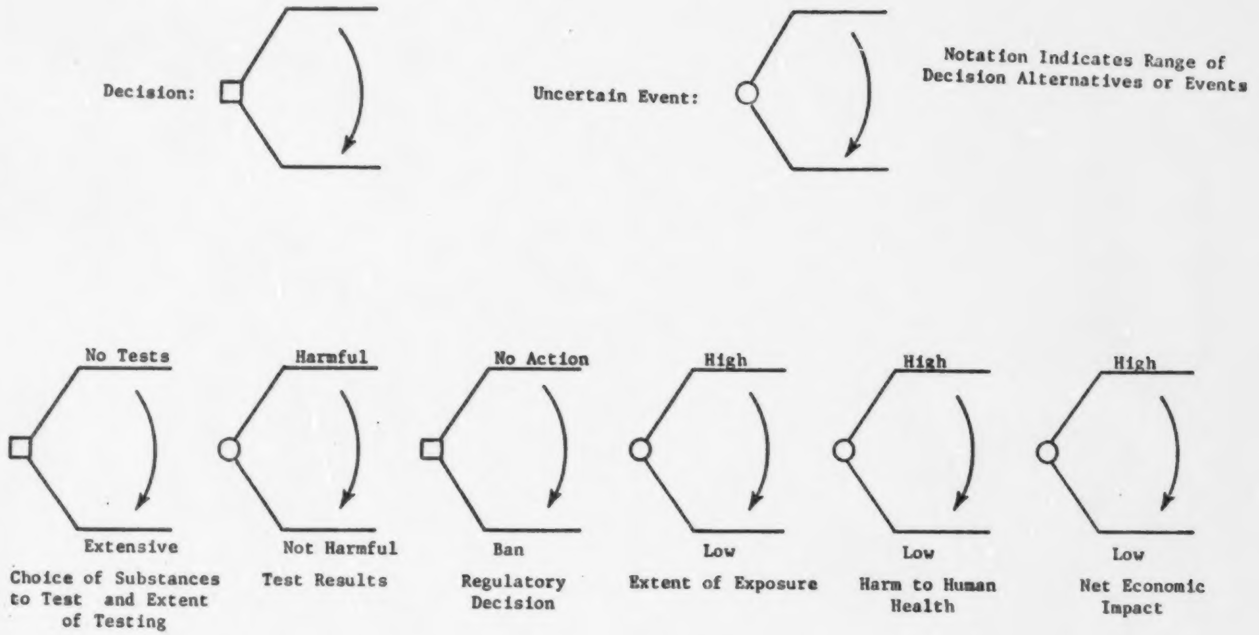

Decision:
Uncertain Event:
Notation Indicates Range of Decision Alternatives or Events
No Tests
Extensive
Choice of Substances to Test and Extent of Testing
Harmful
Not Harmful
Test Results
No Action
Ban
Regulatory Decision
High
Low
Extent of Exposure
High
Low
Harm to Human Health
High
Low
Net Economic Impact

Figure 3-4. Illustrative Generic Decision Tree

$$P(\text{Positive}|\text{Carcinogen}) = 0.85$$
$$P(\text{Positive}|\text{Not Carcinogen}) = 0.20$$

Continuing from our earlier example, based on structure-activity relationships and other available information prior to carrying out the test, we felt that

$$P(\text{Carcinogen}) = 0.1$$

Now, suppose the test is performed and the result is positive. How should we "update" our probability that XYZ is a carcinogen, given this new information? More precisely, we need to calculate

$$P(\text{Carcinogen}|\text{Positive})$$

We can calculate this new conditional probability using a simple rule from probability theory known as Bayes Theorem [64,67]. In terms of arbitrary events A and B, the theorem states that

$$P(B|A) = \frac{P(A|B) \times P(B)}{P(A)}$$

In our example, "B" is "Carcinogen," while "A" is a "Positive" test result. Since we know P(A|B) and P(B), we must first find P(A), or P(Positive). This is straightforward, again following the rule of probability:

$$\begin{aligned} P(\text{Positive}) &= P(\text{Positive and Carcinogen}) \\ &\quad + P(\text{Positive and Not Carciogen}) \\ &= P(\text{Positive}|\text{Carcinogen}) \times P(\text{Carcinogen}) \\ &\quad + P(\text{Positive}|\text{Not Carcinogen}) \\ &\quad \times P(\text{Not Carcinogen}) \\ &= 0.85 \times 0.1 + 0.2 \times 0.9 \\ &= 0.265 \end{aligned}$$

Now we can use Bayes Theorem to find the updated probability that XYZ is a carcinogen:

$$\begin{aligned} P(\text{Carcinogen}|\text{Positive}) &= \frac{P(\text{Positive}|\text{Carcinogen}) \times P(\text{Carcinogen})}{P(\text{Positive})} \\ &= \frac{0.85 \times 0.1}{0.265} \\ &= 0.32 \end{aligned}$$

Note that even though the test was positive we still are not certain that XYZ is carcinogenic. The test itself was uncertain and does not give us "perfect" information on carcinogenicity.

The Value of Information. We noted earlier that it is a tenet of decision analysis--and a mandate to the EPA--to make a decision even when uncertainty is great. To do nothing is always an alternative, but the choice of this alternative should be made explicitly and not by default. Another alternative is also usually available: to gather more information. This is particularly relevant to options under TSCA for testing, monitoring, and data reporting. The decision analysis methodology can give explicit guidance as to when it is worthwhile to obtain more information and can help indicate which information will be the most valuable. This is carried out by calculating the "value of information," based on the idea that new information has value if it reduces uncertainty and allows us to make better decisions.

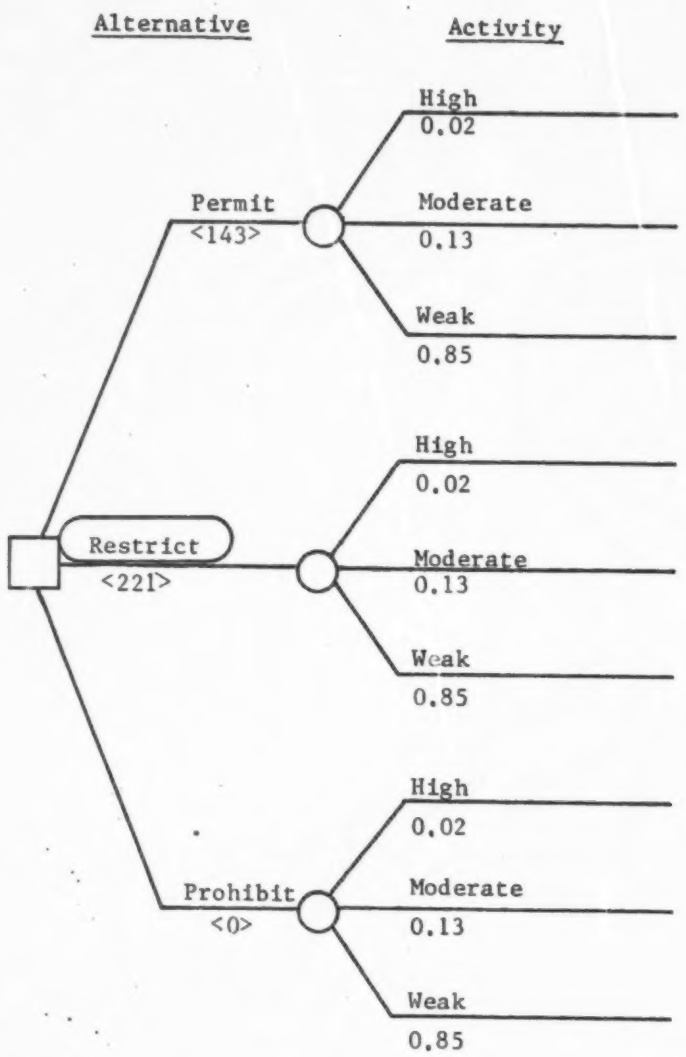
> Is the information that will be acquired by carrying out a test worth the cost of the test? This question will occur repeatedly in toxic substances unreasonable risk decisions. It is a question that the decision analysis methodology is well equipped to answer. We approach the problem by calculating the "expected value of perfect information," or EVPI. The idea is, how much would you pay a clairvoyant to tell you, in advance, what was going to happen (or whether, for example, a substance really is carcinogenic)? If the new information would in no case change your decision, you would not be willing to pay the clairvoyant much, if anything. If it would help make a better decision, then the information has value. The EVPI gives an upper bound on this value.
>
> As an example, consider a highly simplified decision: should the use of the substance XYZ be banned due to its possible carcinogenicity? The three alternatives were identified previously: to prohibit all uses, to restrict use to the current industrial applications, or to permit all uses including the new consumer adhesive. Assume that a preliminary analysis has indicated that the key uncertainty is the degree of dose response activity of XYZ. As a simple approximation, we consider three possibilities: XYZ could be highly active, inducing cancer at low doses; it could be moderately active, causing cancer at high dose levels; or it could be weakly active, with cancerous tumors occurring only when the most susceptible individuals receive very large doses. Based on structure-activity relationships, the judgment of those knowledgeable about the properties of XYZ is that there is a 2 percent chance that it is highly active, a 13 percent change that it is moderately active, and an 85 percent chance that it is weakly active.

The alternatives and possible outcomes are summarized in the decision tree of Figure 3-5a. Higher activity implies a greater number of cases of cancer, as does permitting widespread use. The net value consists of the net economic benefits (we have added benefits to industry and benefits to consumers to simplify the figure) less the cancer cases times the tradeoff of ten million dollars. Under each alternative is shown the expected value (the arithmetic average of the values of the uncertain outcomes) for that alternative, enclosed in angle brackets. We would choose the restrict alternative, since it has the greatest expected value ($221 million); we note this by circling the alternative.

How would the decision change if we knew in advance what was the actual degree of activity of XYZ? If we knew that it was highly active, to ban its use would clearly be the preferred alternative. If it was only weakly active, then it would be best to permit all uses so as not to forego the economic benefits of use. This situation is summarized in Figure 3-5b. Given our prior state of uncertainty, we would expect a 2 percent chance that the clairvoyant would tell us that XYZ was highly active (implying that we would choose to ban its use) and an 85 percent chance that it was weakly active (implying we would permit all uses). The average, or expected value given the clairoyant's information is 761 million. The increase in expected value due to our receiving the information on carcinogenicity--the EVPI--is 761 less 221, or 540 million. This figure provides an upper bound on the value of information about the dose-response activity of XYZ.

As was noted in the previous example, one can rarely acquire perfect information. Tests are not 100 percent precise. Using the same procedure just outlined, one can calculate the expected value of the information provided by any test [31,63,64]. Although the idea is the same, the calculations are somewhat more complicated; we shall not go through them here.

In light of the vast number of uncertain factors involved in a determination of unreasonable risk, one might reasonably ask, How can we make probability assignments for every one? And even if we could, what would we do with that mass of numbers and judgments? The answer is, We do not specify probabilities for all of the variables and relationships--only for those that are the most important. The measure of importance is a simple one: Does the uncertainty in this variable (or relationship) affect the


Alternative
Activity
Permit
<143>
Restrict
<221>
Prohibit
<0>
High
0.02
Moderate
0.13
Weak
0.85
High
0.02
Moderate
0.13
Weak
0.85
High
0.02
Moderate
0.13
Weak
0.85

Alternative	Activity	Cancers Annually	Net Economic Benefits of Use ($$\times 10^6$)	Net Value ($\times 10^6$)
Permit <143>	High 0.02	1,100	900	-10,100
	Moderate 0.13	400	900	-3,100
	Weak 0.85	2	900	880
Restrict <221>	High 0.02	700	400	-6,600
	Moderate 0.13	30	400	100
	Weak 0.85	0	400	400
Prohibit <0>	High 0.02	0	0	0
	Moderate 0.13	0	0	0
	Weak 0.85	0	0	0

Figure 3-5a. Decision Under Uncertainty

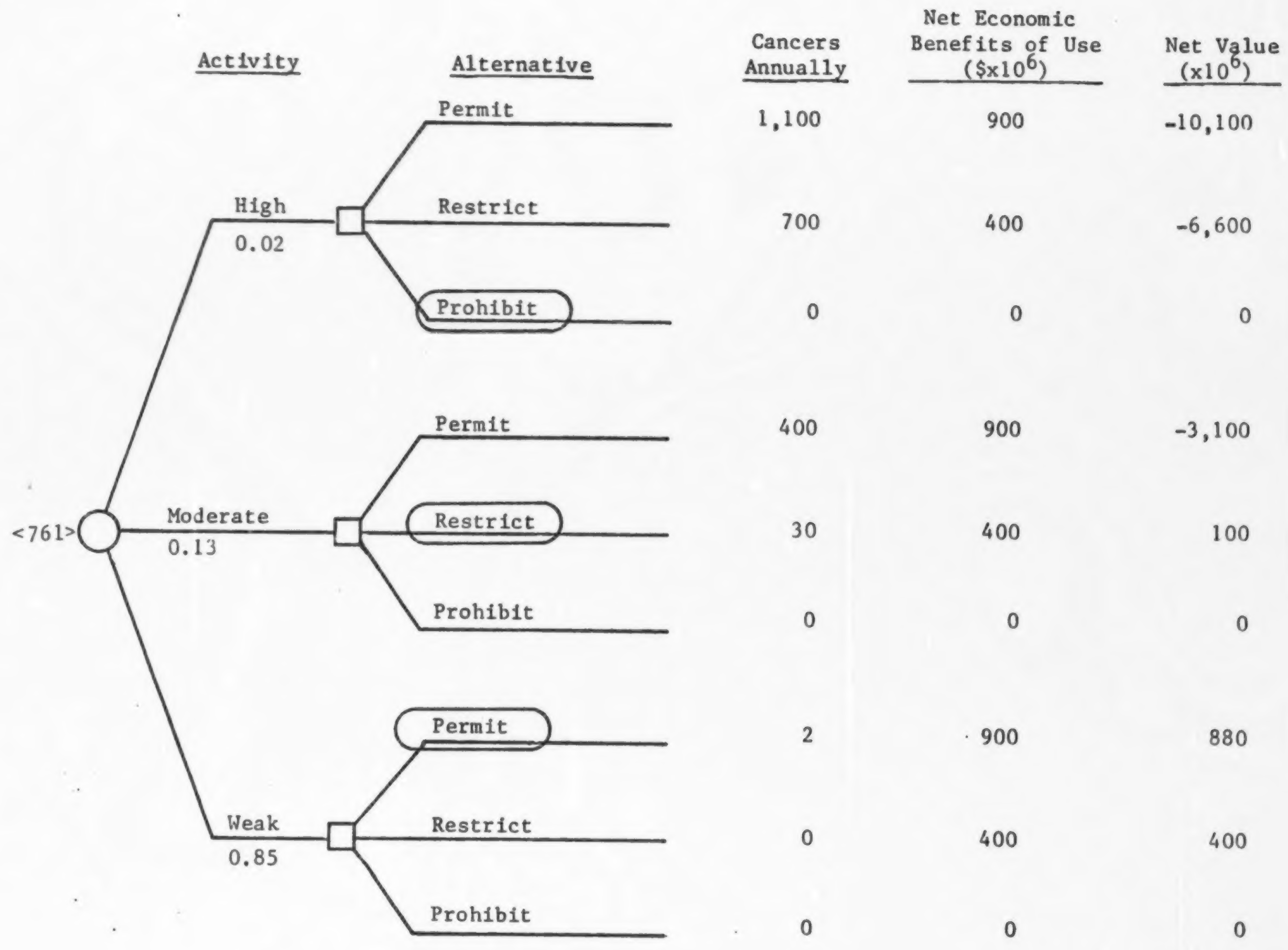

Activity
Alternative
Cancers Annually
Net Economic Benefits of Use ($x10^6)
Net Value (x10^6)
<761>
High
0.02
Permit
1,100
900
-10,100
Restrict
700
400
-6,600
Prohibit
0
0
0
Moderate
0.13
Permit
400
900
-3,100
Restrict
30
400
100
Prohibit
0
0
0
Weak
0.85
Permit
2
900
880
Restrict
0
400
400
Prohibit
0
0
0

Figure 3-5b. Decision with Perfect Information

outcomes enough to change the preferred decision alternative? For most decisions only a relatively small number of uncertain parameters and relationships are really critical.

The way we determine the critical uncertainties is by using a key part of the decision analysis methodology--sensitivity analysis. Before discussing sensitivity analysis in any detail we will outline the structural model used to integrate the information, uncertainties, and decision alternatives. Such a model is a key tool for carrying out sensitivity analysis and plays a central role in the entire decision analysis methodology.

Integrating Model

Complexity is all pervasive in the toxic substances unreasonable risk determination process. There are many ways in which a substance can be used, many ways in which it might be harmful, and many groups in society that it can affect. The chemical and biological processes are exceedingly complex. Even the economic system is complicated, with intermediate products, substitutes, complements, multistage production processes, and diverse markets.

In the face of such complexity, intuition is often a poor and misleading guide. The alternative to relying strictly on intuition is modeling the complex interactions--representing them explicitly so that our intuition is not burdened with keeping track of a great many different interactions. The decision analysis methodology uses a structural model to fill this role.

The purposes of a structural model are to integrate information from a variety of sources, to represent critical interactions, to provide a consistent and explicit set of assumptions, and to facilitate sensitivity analysis. By structural model we mean an explicit representation of one's understanding and assumptions about the underlying relationships among the various aspects of the decision problem. Referring back to Figure 3-1, the model represents how the EPA's decisions interact with the economic, physical, and biological systems to affect the outcomes. It is "structural" in the sense that it is based as much as possible on a basic understanding of the relationships and interactions involved in the problem--economic market processes, dose response relationships, and so on.

An important advantage of building an explicit structural model is that it provides an explicit, common framework for experts from diverse fields to make contributions. Assumptions are clearly evident, and the overall model can be examined and calculations verified by any individual interested in the analysis.

The nature and content of the model depends critically on the decision being analyzed. Any toxic substances decision will involve economic factors, physical processes of transport and exposure, and effects on humans and/or the environment. Thus, we can outline a generic model in more detail than in Figure 3-1. This is shown in Figure 3-6. The diagram depicts the key submodels and indicates some of the important variables through which the submodels interact.

Beginning with the generic model and a specification of the particular unreasonable risk decision, the analysts can begin to define each submodel. Although there are many steps in the development of a final structural model, starting from prose statements of assumptions, the model's final form is usually a set of mathematical statements representing the basic relationships. The degree of detail depends on the specific decision and the stage of the analysis. Initially, a model might have only a few equations. If sensitivity analysis indicates that a particular aspect of the problem is critical, it can then be modeled in more detail, with more factors represented and more second- or third-order interactions included.

> As a simple example, consider a human exposure submodel. Its purpose is to calculate the aggregate dose received by consumers, during a given period of time. As shown in Figure 3-7a, inputs to the exposure model would include total quantity of XYZ produced, the fraction used in consumer products, and the fraction ingested in consumer use. Such a simple model would incorporate equations to account for the flow and mass-balance of XYZ, and to compute the average dose.
>
> A more detailed exposure model is outlined in Figure 3-7b. It disaggregates exposure by different populations, such as consumer exposure and occupational exposure. Total exposure to an individual is a sum of exposures through several possible pathways, including

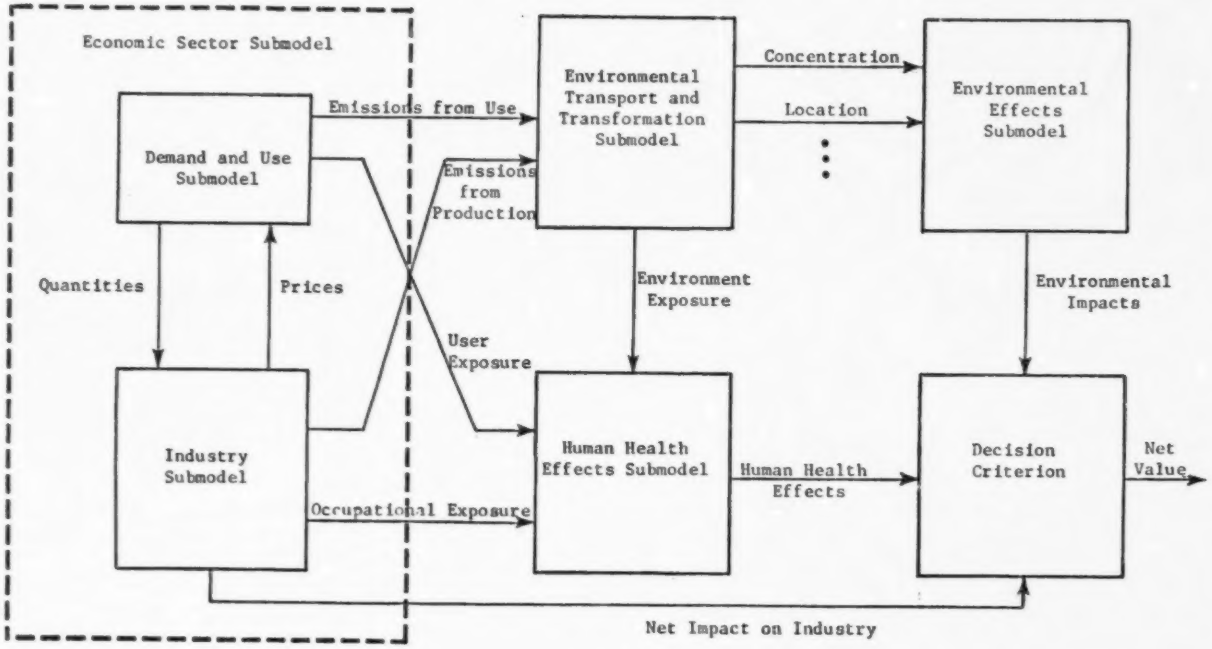

Economic Sector Submodel
Demand and Use Submodel
Industry Submodel
Quantities
Prices
Emissions from Use
Emissions from Production
User Exposure
Occupational Exposure
Environmental Transport and Transformation Submodel
Human Health Effects Submodel
Concentration
Location
Environment Exposure
Environmental Effects Submodel
Environmental Impacts
Human Health Effects
Decision Criterion
Net Value
Net Impact on Industry

Figure 3-6. Decision Analysis Integration Model

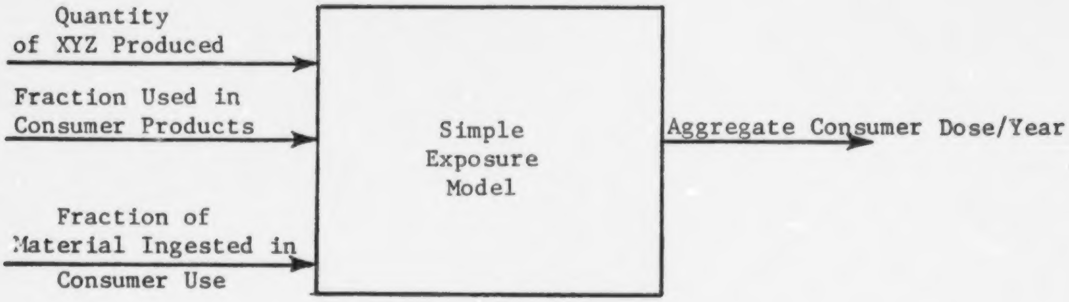

Quantity of XYZ Produced
Fraction Used in Consumer Products
Fraction of Material Ingested in Consumer Use
Simple Exposure Model
Aggregate Consumer Dose/Year

Figure 3-7a. Simple Exposure Model

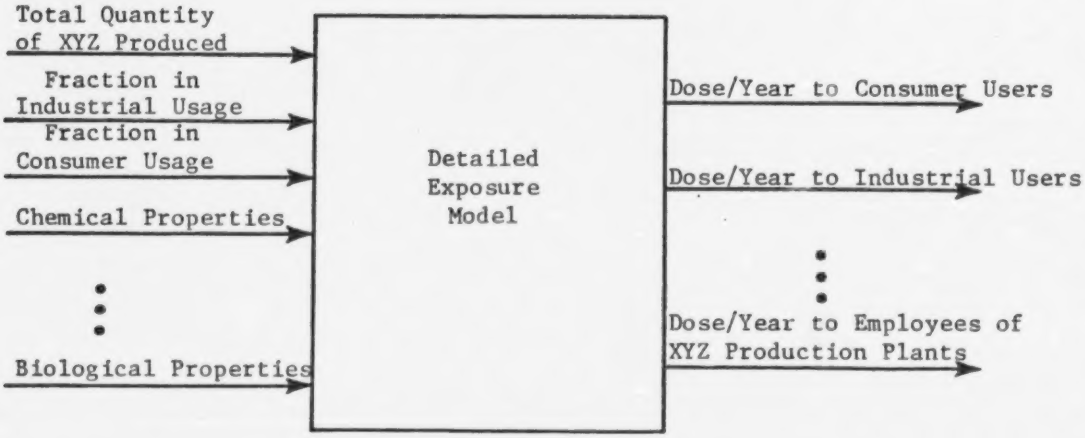

Total Quantity of XYZ Produced
Fraction in Industrial Usage
Fraction in Consumer Usage
Chemical Properties
Biological Properties
Detailed Exposure Model
Dose/Year to Consumer Users
Dose/Year to Industrial Users
Dose/Year to Employees of XYZ Production Plants

Figure 3-7b. Detailed Exposure Model

> consumer use and through environmental residues. Each pathway would include the relevant steps from the manufacturing of XYZ, to its use in a product, to its release, and finally to its ingestion, absorption, or inhalation by an individual. The model would include equations to represent chemical and biological processes such as decomposition and bioaccumulation, as well as the simpler equations for mass-balance accounting.

Structural modeling will play a particularly important role in helping our understanding of the economic implications of toxic substances decisions. Issues of substitution, market shares, and effects on feedstocks and final consumer products will all be important. A central role is played by economic markets, wherein chemical substances and products using such substances compete. In order to calculate economic costs and benefits, it is necessary to estimate market equilibrium prices and quantities. One way to approach this problem is to use an economic modeling methodology known as generalized equilibrium modeling [65]. The basic idea is to think about an economic sector in terms of a network of industries, consumers, and markets. An example will illustrate the approach.

> To evaluate the economic impact of the possible regulation of XYZ, it is necessary to understand the processes of market competition and interproduct substitution. For example, if a product using XYZ is removed from the market as a result of regulatory action, there will be direct economic losses, but they will be partially offset by increased sales of competing products. Three markets are central to the analysis of XYZ: the market for the XYZ resin itself, the market for consumer adhesives, and the market for industrial adhesives.
>
> A portion of the economic sector in which the resin XYZ plays a role is depicted by Figure 3-8. Circles represent simple models o economic markets. Boxes represent models of production or conversion processes, or of a final demand for a good. Final demands are at the top of the network, while basic resource supplies are at the bottom. Materials flow "up" the network, undergoing various conversions and being traded in explicit markets. Note that both industrial and the new consumer adhesive manufacturing processes compete for a supply of XYZ resin, which can be produced by either of two processes. Adhesives using XYZ compete with alternative adhesives in both the industrial-use and consumer-use markets. A network model such as that summarized in Figure 3-8 can be used to trace the implications of regulatory actions as they propagate through the economic system.

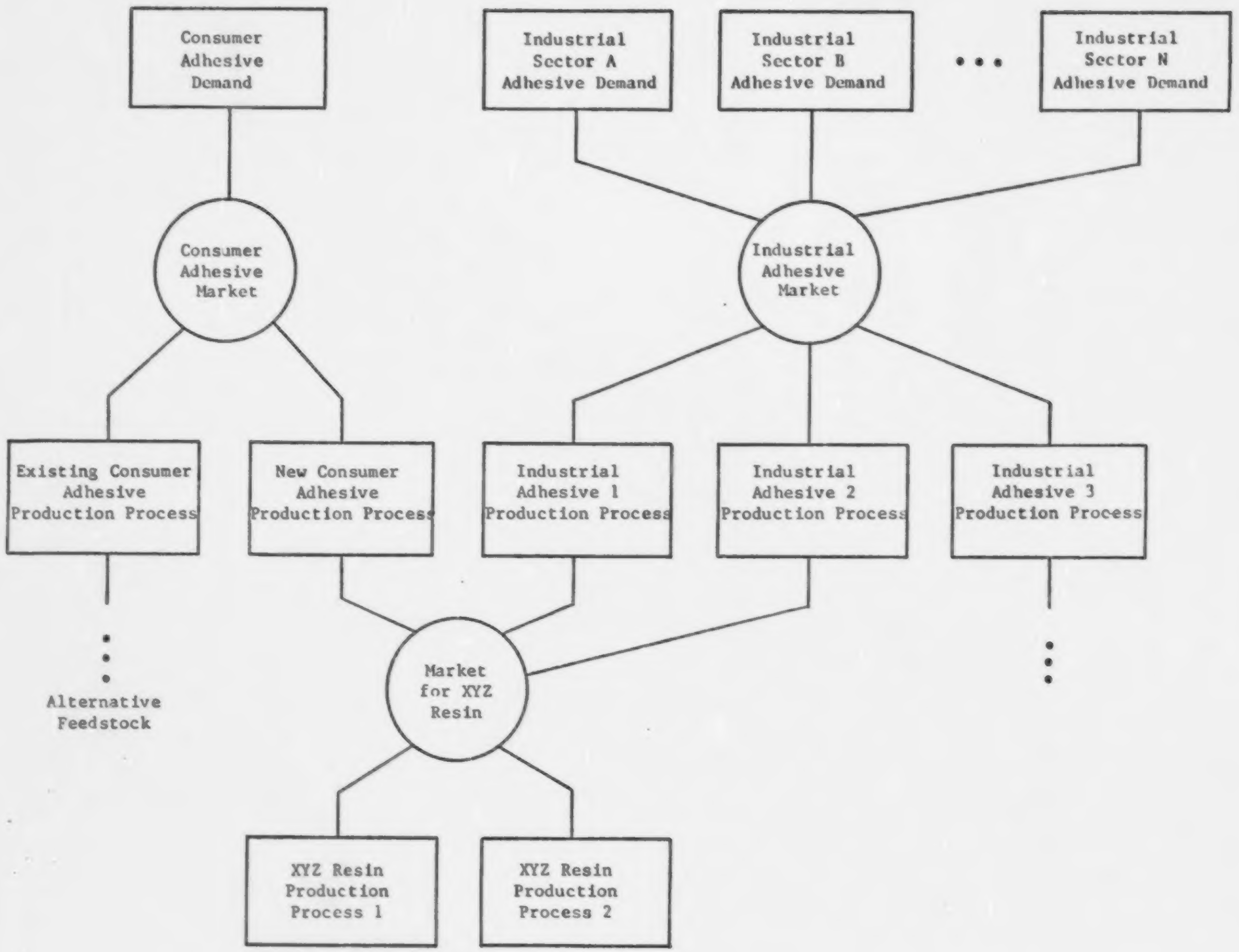

Consumer Adhesive Demand
Industrial Sector A Adhesive Demand
Industrial Sector B Adhesive Demand
• • •
Industrial Sector N Adhesive Demand
Consumer Adhesive Market
Industrial Adhesive Market
Existing Consumer Adhesive Production Process
New Consumer Adhesive Production Process
Industrial Adhesive 1 Production Process
Industrial Adhesive 2 Production Process
Industrial Adhesive 3 Production Process
• • •
Alternative Feedstock
• • •
Market for XYZ Resin
XYZ Resin Production Process 1
XYZ Resin Production Process 2

Figure 3-8. Illustrative Economic Network

> The simple models of markets and production processes include representations of both physical processes and economic behavior. The generalized equilibrium modeling approach can be used to "solve" the network, providing a set of equilibrium prices and quantities over time which can be used to calculate net economic impacts of regulatory options.
>
> Economic network models are a flexible yet powerful way of customizing a model to capture the economic interactions important to a specific unreasonable risk decision. Detail can be added as necessary, while retaining a good intuitive representation of the economy.

Once a structural model has been developed, it provides a tool to estimate "what happens," that is, what outcomes are obtained given each decision alternative. The model provides the linkage between the information we have about the specific problem ("what we know"), the regulatory alternatives ("what we can do"), and the outcomes that enable the decision maker to judge the desirability of each alternative ("what we want").

Sensitivity Analysis

Although sensitivity analysis is a key methodological concept, it is an intuitively simple idea. The basic idea is to find out whether something in the decision problem about which we are uncertain is important. Something is important if it affects the decision, that is, if changes in the parameter or relationship change the preferred decision alternative.

Although sensitivity analysis is used throughout the decision analysis process, it plays a critical role at two stages. The first is when the structural model is being developed. There may be several alternative formulations of a particular relationship that are being considered for use in the model. A simple version of each can be tried out and the impact on the outcomes observed. If the outcomes change little, we can assume that the decision is unlikely to change and that it is reasonable to go ahead and choose the "most likely" model relationship. If the outcomes change considerably, this suggests either that more detailed modeling is necessary or that the uncertainty must be represented explicitly using probability assignments. As the model is developed, we can continue to use sensitivity analysis to help guide our choices in terms of modeling effort and degree of detail.

Once a first-cut model is complete, including specification of a decision criterion, sensitivity analysis is carried out on each of the (perhaps numerous) uncertain variables. As previously noted, although a variable may be highly uncertain, we will always have enough information to define a range (perhaps very broad) of possible values. To perform the sensitivity we vary the value of the variable over its maximum possible range and observe the impact on the decision. If the outcomes do not change enough to change the decision, then the uncertainty in the variable is not critical. A "best estimate" for its value can be used in the remainder of the analysis. If the decision changes, the uncertainty should be represented explicitly and factored into the analysis.

> The sensitivity analysis might be displayed in a form similar to that demonstrated in Table 3-1. The table shows the sensitivity of the outcomes, net value, and regulatory decision to the uncertainty in two variables. The first uncertainty is in the number of consumers exposed to XYZ. Upon examining the net value under each alternative, it is apparent that the "restrict use" alternative is preferred over the full range of uncertainty in the population size. Since the decision is not affected, the nominal value or "best estimate" can be used.
>
> The net value is much more sensitive to variations in the average dose level, a highly uncertain variable. If the dose is high, the best alternative is to prohibit all uses, while it would be preferable to permit all uses if the actual dose value were low. Because the decision is sensitive to the uncertainty in dosage level, the uncertainty should be represented explicitly in the analysis. This can be done using a probability distribution.

It is important to remember that sensitivity analysis is a conceptual idea as well as a methodological procedure. It can be applied qualitatively as well as quantitatively. This simply involves the analyst or decision maker's asking at each step of the process, "Does it matter to the specific decision?" This applies when defining the decision and the details of alternatives, when choosing outcomes to examine, and when evaluating informaton that might be factored into the analysis. In many cases

Table 3-1

EXAMPLE SENSITIVITY ANALYSIS RESULTS

	(1) Permit All Uses			(2) Restrict Use			(3) Prohibit All Uses		
	Number of Cancers	Economic Benefits*	Net Value	Number of Cancers	Economic Benefits	Net Value	Number of Cancers	Economic Benefits	Net Value
1. Size of Exposed Population									
High - 8,000	410	900	-3,200	38	400	20	0	0	0
Nominal - 6,000	400	900	-3,100	30	400	100	0	0	0
Low - 3,000	370	900	-2,800	15	400	250	0	0	0
2. Average Dose Level									
High - 0.9 gram/yr.	1400	900	-13,100	70	400	-300	0	0	0
Nominal - 0.2 gram/yr.	400	900	-3,100	30	400	100	0	0	0
Low - 0.03 gram/yr.	10	900	800	8	400	320	0	0	0

---

*Economic benefits and net value are all x 10^6

one can do a qualitative sensitivity analysis, note the conclusion, and simpify the analysis accordingly.

Probabilistic Analysis

In the process of carrying out the sensitivity analysis we will have identified a set of uncertain variables for which the uncertainty really matters; that is, the unreasonable risk decision is sensitive to such uncertainties. Given all available data and the judgments of EPA staff, probability distributions will be specified to represent each uncertain variable explicitly.

The next stage in the decision analysis process is to carry out a full probabilistic analysis, using the integrating model and probability distributions on the critical parameters to generate probability distributions on the outcomes. One might visualize this as shown in Figure 3-9, which depicts only a portion of the integrating model, a simplified cancer occurrence submodel. Probability distributions on exposure, number exposed, and response function parameters are combined using the equations of the model to produce a probability distribution on the number of cancers. This latter distribution explicitly represents the uncertainty in a critical outcome resulting from the uncertainty in the input data. An analysis summary presented to EPA decision makers should include for each alternative a description of the range of uncertainty in each of the important outcomes.

Outcome probability distributions are calculated by using a decision tree to outline probabilistic scenarios. One might think of "driving" the integrating model with the decision tree, as shown in Figure 3-10. Recall that each path through the tree defines a scenario, whose probability of occurrence is equal to the product of the probabilities on each uncertainty node branch. The scenario fixes a set of values for the uncertain parameters. These values, combined with deterministic data, are used by the integrating model to calculate a value for each outcome, a value whose probability of occurrence is equal to the scenario probability. This procedure is carried out for each path through the decision tree, often with

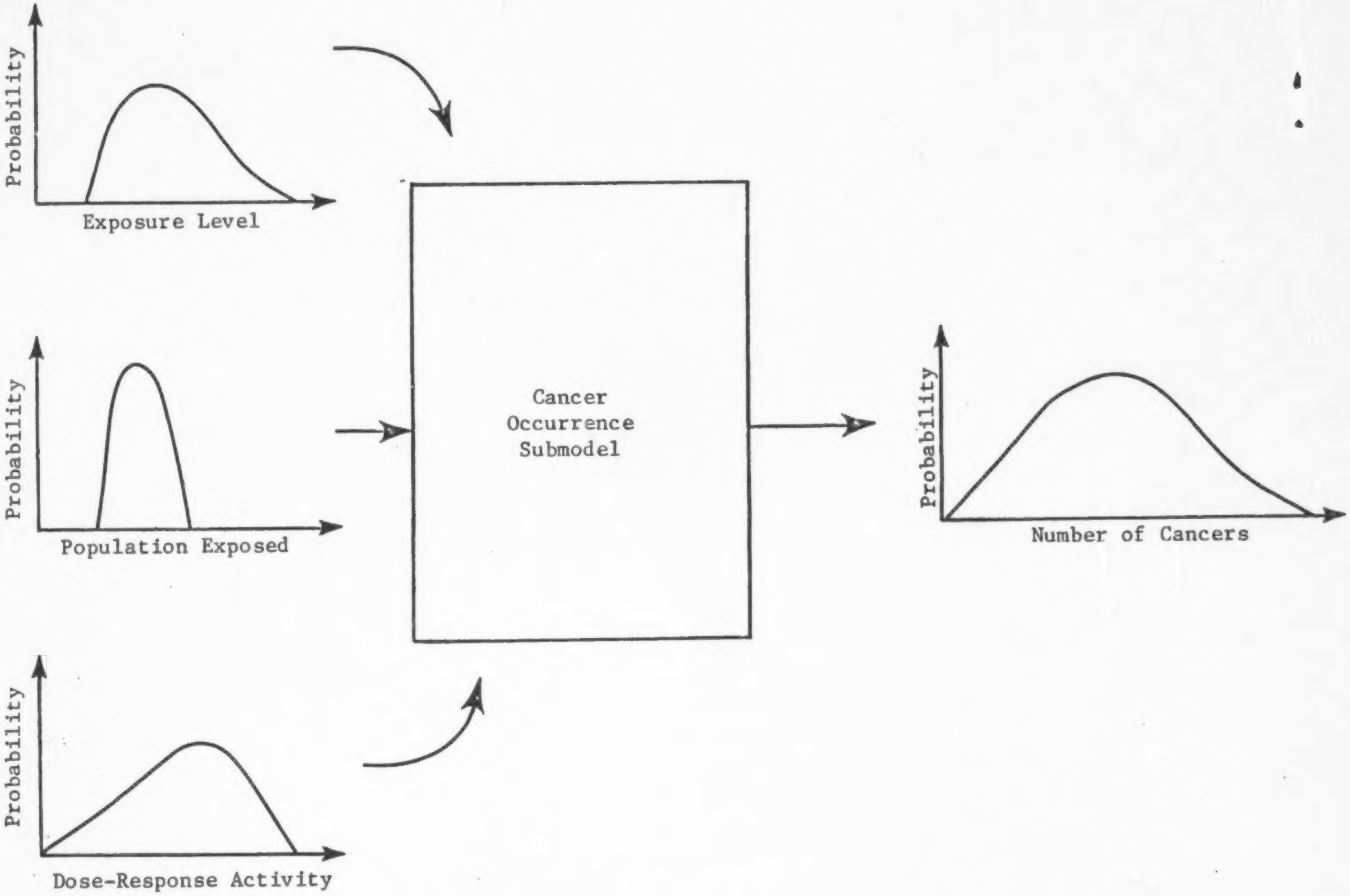

Probability
Exposure Level
Probability
Population Exposed
Probability
Dose-Response Activity
Cancer
Occurrence
Submodel
Probability
Number of Cancers

Figure 3-9. Using Model to Calculate Uncertain Outcome

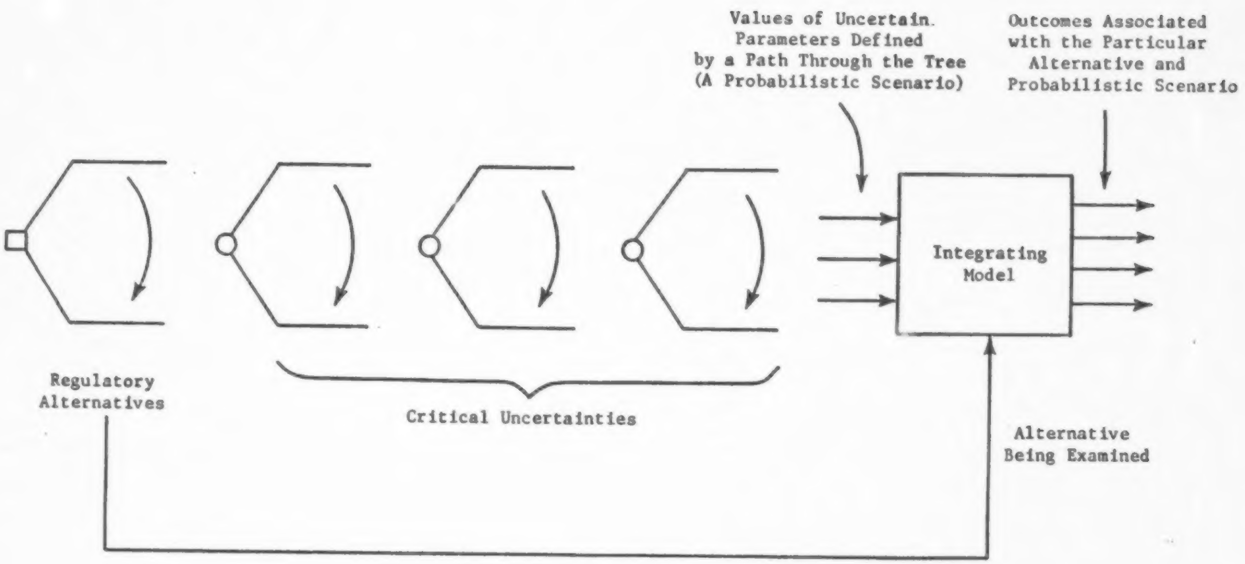
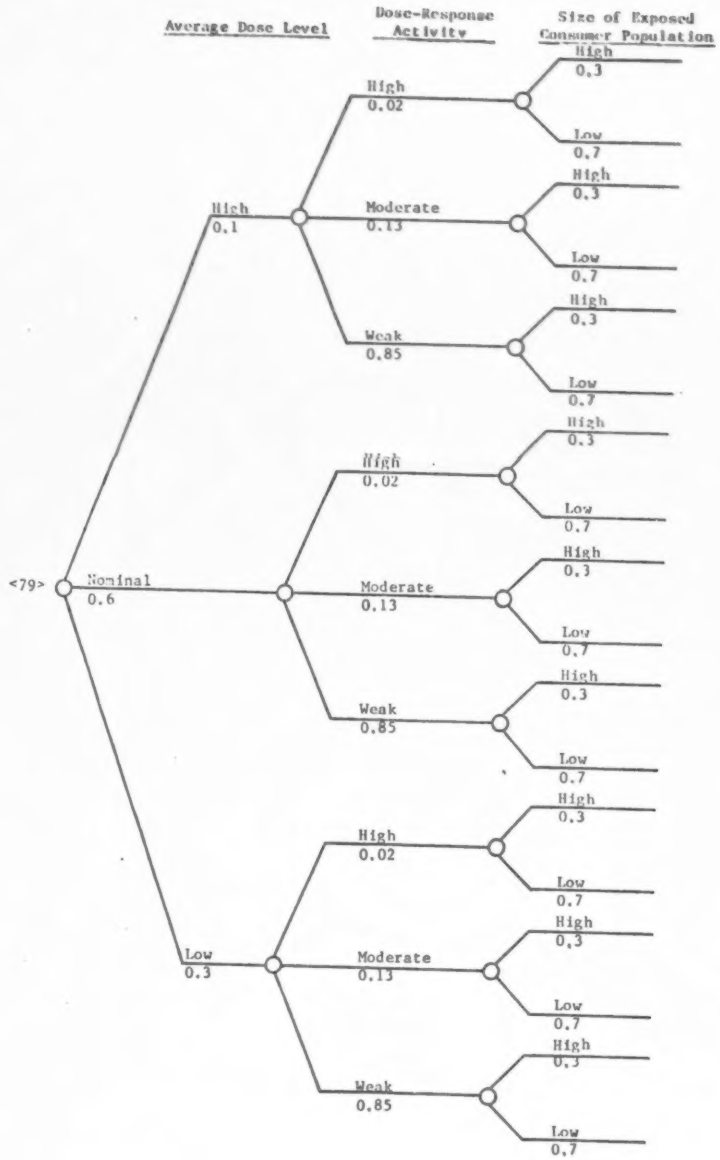

Values of Uncertain. Parameters Defined by a Path Through the Tree (A Probabilistic Scenario)
Outcomes Associated with the Particular Alternative and Probabilistic Scenario
Integrating Model
Regulatory Alternatives
Critical Uncertainties
Alternative Being Examined

Figure 3-10. Relationship of Decision Tree and Integrating Model

the aid of a computer program to carry out the numerous calculations. Combining all the outcome values and associated probabilities gives the overall probability distributions on the outcomes.

> As an example, suppose that the sensitivity analysis has shown that the key uncertainties for the XYZ regulatory decision are dose response activity, average dose level, and the number of consumers exposed. These uncertainties are shown in the probability tree of Figure 3-11 (a decision tree with uncertainty nodes only is known as a probability tree; in this example we are considering only one of the three alternatives in the complete decision tree). We assume that the uncertain parameters are independent.
>
> The first four columns at the right of the tree summarize the outcome values for each path or scenario and the probability of the scenario. The outcomes and the scenario probabilities are combined to give a set of cumulative probability distributions. The probability distribution on the number of cancers can be examined by referring to Figure 3-12 (the horizontal scale is broken at several points because of the wide range of possible outcomes). Note that while there is a 76 percent chance that the number of cancers will be 5 or fewer, there is still a small possibility that it could be as many as 7000. The mean or expected value for the number of cancers is 83. Again, it is important to keep in mind that this is for a single alternative only. With a different alternative, the number exposed would be different, and perhaps the dose would be different, leading to a different probability distribution for the cancer outcome.
>
> While the entire probability distribution shows the range of outcomes and the likelihood of each outcome, it can be somewhat cumbersome. There are several ways to summarize the distribution in more concise terms. The following is one way that retains much of the information on the range and uncertainty in the net value:
>
> mean net value = \$79 million
> probability that net value > 1.4 billion = 10%
> probability that net value > 695 million = 50%
> probability that net value < -2.5 billion = 10%
> probability that net value < -16 billion = 1%

At this point a sensitivity analysis can be conveniently carried out on the cancer tradeoff. The results just summarized used the tentative tradeoff of 10 million. If the tradeoff were one million, the mean net value would be 827 million. On the other hand, if a tradeoff of 20 million were used, the mean net value would become -750 million. By carrying out


Average Dose Level
Dose-Response Activity
Size of Exposed Consumer Population
<79>
High
0.1
Nominal
0.6
Low
0.3
High
0.02
Moderate
0.13
Weak
0.85
High
0.3
Low
0.7

Number of Cancers	Economic Benefits $(x10^6)$	Net Value $(x10^6)$	Path Probability
7,000	1,400	-68,600	0.0006
2,600	700	-25,300	0.0014
3,000	1,400	-28,600	0.0039
1,200	700	-11,300	0.0091
50	1,400	900	0.0255
20	700	500	0.0595
1,900	1,400	-17,600	0.0036
800	700	-7,300	0.0084
600	1,400	-4,600	0.0234
300	700	-2,300	0.0546
5	1,400	1,350	0.1530
1	700	690	0.3570
900	1,400	-7,600	0.0018
400	700	-3,300	0.0042
80	1,400	600	0.0117
30	700	400	0.0273
0	1,400	1,400	0.0765
0	700	700	0.1785

Figure 3-11. Example Probabilistic Analysis for "Permit All Uses" Alternative

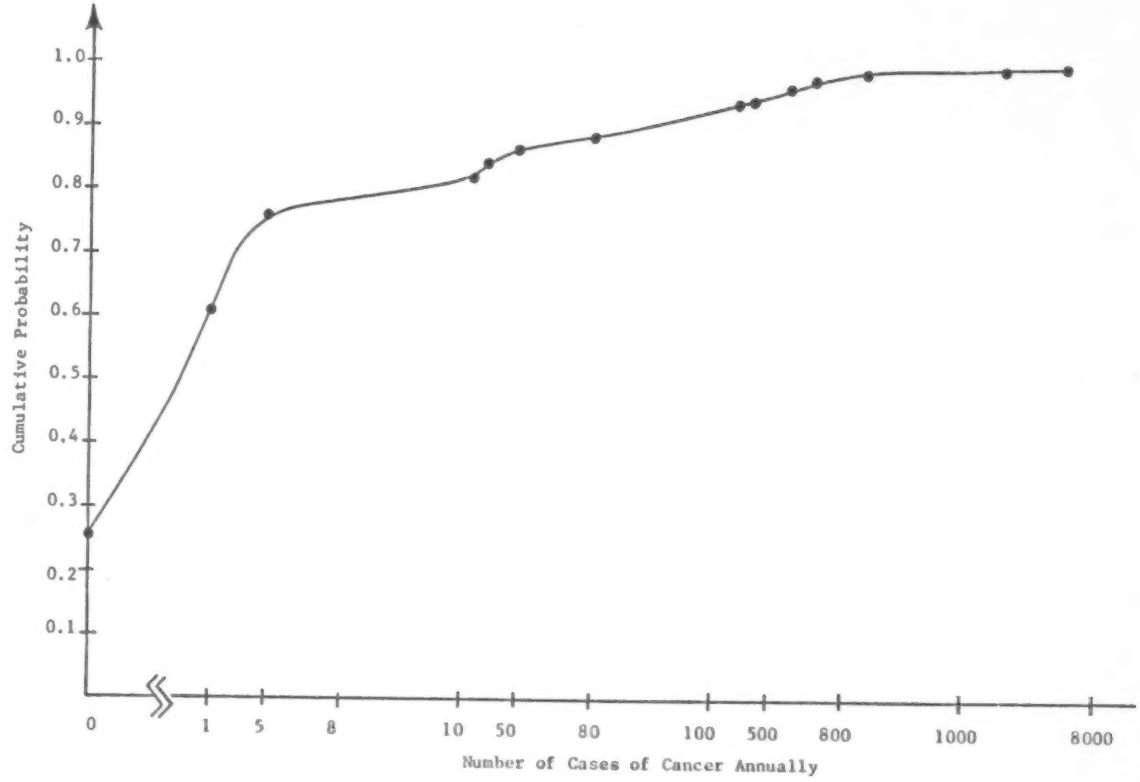


Figure 3-12. Cumulative Probability Distribution on the Number of Cases of Cancer

similar sensitivity tests for each of the other alternatives, sensitivity of the unreasonable risk determination to the tradeoff value can be evaluated.

The final step in the probabilistic analysis is to calculate the value of information for each uncertain parameter for which information-gathering alternatives exist.

The "results" of an unreasonable risk decision analysis presented to EPA decision makers should include, at a minimum, the following:

1. Definition of alternatives considered and outcomes evaluated.
2. Description of the integrating model, including an explicit list of key assumptions.
3. Documentation of the initial data and of the sensitivity analysis.
4. Probability distributions for the critical uncertainties identified in the sensitivity analysis.
5. For each alternative, the expected value, range, and probability distribution (or summary thereof) for each outcome and for the overall desirability of the alternative.
6. The expected value of perfect information on relevant parameters.
7. The expected value of the (imperfect) information to be gained from potential testing or other information-gathering alternatives.

Summary of the Decision Analysis Process

Having discussed the methodology of decision analysis in some detail, we would like to step back and review some of the key points made at the outset. It cannot be overemphasized that the primary purposes of carrying out an unreasonable risk decision analysis are to improve our understanding of the decision problem and to gain insights into the critical issues. While the quantitative results are important, the qualitative understanding is the real goal. This understanding will come as much from the process of the analysis--structuring the problem, developing a model, testing assumptions, carrying out sensitivity analyses, and so on--as from examination of the analysis results. For this reason we maintain that the process of the analysis as well as the conclusions must be documented.

We have noted several times that decision analysis is an iterative and evolutionary process. As the analysis proceeds and we understand the problem better, we are likely to go back to a previous step and refine the model or modify a decision alternative. This is particularly the case with the sensitivity analysis phase, which often iterates back and forth several times between model improvements and sensitivity tests. In the probabilistic phase, new information can be factored in and the probability distributions recalculated to reflect what has been learned. The process is iterative and flexible but always carried out in a consistent manner within the overall decision analysis framework.

Complementing the iterative nature of the process is the fact that the decision analysis methodology can be applied at almost any level of detail, from a quick "back-of-the-envelope" calculation to a fully disaggregated, multiregional analysis. The level of detail used should be appropriate to the nature of the decision and the time and resources available for the analysis. Whatever the level of detail, the decision analysis approach focuses attention and effort on the key issues and critical uncertainties, providing a maximum of useful, insightful information for the decision makers.

COORDINATION OF DECISIONS

We have described a decision analysis methodology for evaluating a toxic substances unreasonable risk decision, or closely related set of decisions. The problem facing the EPA as it implements TSCA has another critical dimension: the coordination of an enormous number of individual decisions, decisions that must be made with respect to different substances, at different stages in the evaluation of a single substance, and at different points in time. It is essential that these decisions be made in a consistent manner, that analytical resources be optimally utilized, and that the EPA be able to set priorities for action.

In this section we outline some of the ideas that can provide the basis for developing a system for coordinating TSCA decision making. Collectively, these ideas are the fundamental principles of decision system analysis [66,67], the methodology for analyzing in a coordinated and efficient manner a large number of interrelated decisions. In particular, decision system analysis allows us to deal with the interactions caused by uncertainty and by the fact that limited regulatory resources must be allocated to a relatively small number of substances selected from an enormous initial group. The concepts of decision system analysis are especially useful in situations characterized by multiple levels of decision making, as are found in the EPA TSCA program.

Decision system analysis is based on three principles: decomposition, coordination, and iteration. Decomposing the overall toxic substances problem into a set of semi-independent regulatory decisions considerably reduces the magnitude of the problem. Since these individual decisions are not completely independent, they must be coordinated to account for their interactions. Coordination is provided by common value tradeoffs and assumptions about such general factors as economic growth and inflation. Finally, rather than attempt to arrive at an "optimal" decision in one step, we proceed in an iterative fashion, revising and refining the decision as more information is received and more factors are worked into the analysis. This is a familiar problem-solving process that goes on in an informal way in innumerable situations. Decision system analysis provides the formal principles necessary for applying it in a rigorous and consistent way to such complex problems as toxic substances regulation.

Decision system analysis provides the overall logical approach that the EPA can use to develop a framework for coordinated decision making with respect to priority setting and unreasonable risk determination. It can be applied along two general dimensions: the coordination of a sequence of decisions for a single substance and the analysis of decisions regarding different substances. One way in which these decisions might fit together in a coordinated framework is shown in Figure 3-13.

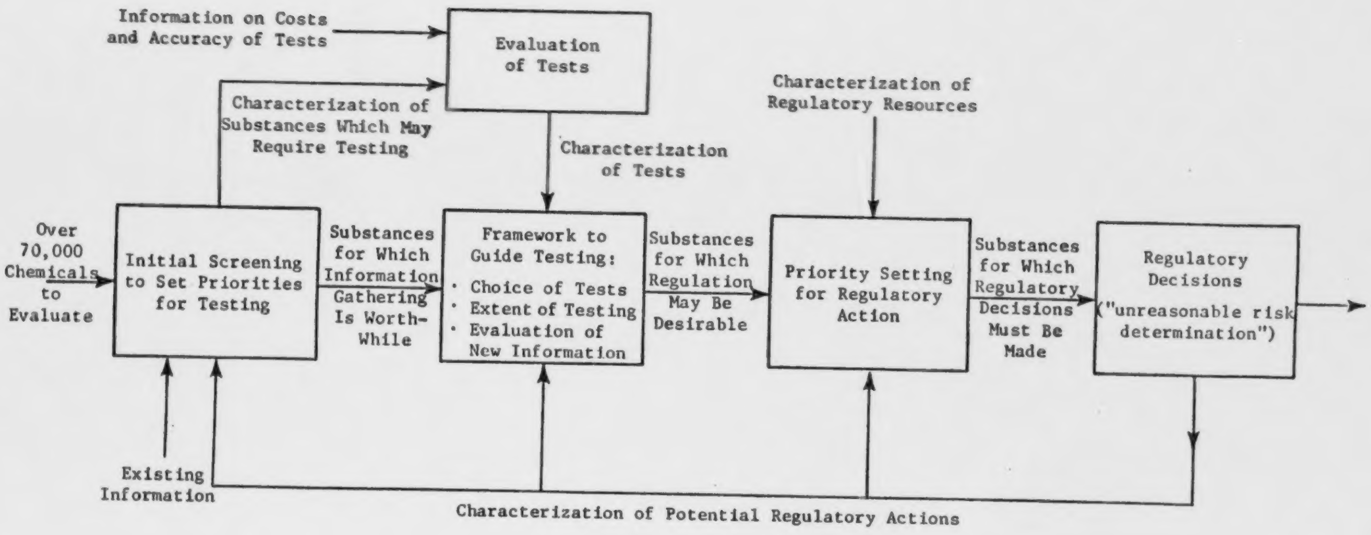

Information on Costs and Accuracy of Tests
Evaluation of Tests
Characterization of Substances Which May Require Testing
Characterization of Tests
Characterization of Regulatory Resources
Over 70,000 Chemicals to Evaluate
Initial Screening to Set Priorities for Testing
Substances for Which Information Gathering Is Worth-While
Framework to Guide Testing:
· Choice of Tests
· Extent of Testing
· Evaluation of New Information
Substances for Which Regulation May Be Desirable
Priority Setting for Regulatory Action
Substances for Which Regulatory Decisions Must Be Made
Regulatory Decisions ("unreasonable risk determination")
Existing Information
Characterization of Potential Regulatory Actions

Figure 3-13. Overview of a Coordinated Framework for Decision Making

Coordination Among Decision Stages

Decisions regarding a particular chemical or class of chemicals range from initial screening and priority setting to a final determination of unreasonable risks. The decisions at the earlier stages (see Figure 3-13) must in general be made more quickly and with less analytical effort. As we move from the initial stages of screening and testing decisions to the final regulatory decision analysis, we are able to add greater detail and structure to the analysis. Yet it is essential that the assumptions and approximations used in the initial stages be consistent with the more detailed analysis at the final stage. One way to do this is to have the basic core structure of the model be essentially the same at each decision stage. As we move toward a more detailed decision, we might add

- Greater detail and disaggregation in the time dimension--a dynamic rather than static analysis.
- Disaggregation of the parties (or populations) bearing the costs and receiving the benefits from the use of a substance.
- Greater attention to second-order effects.

Another way in which the initial stages could approximate a detailed model is by directly assessing probability distributions on key variables rather than using a model. Later, in the regulatory decision analysis, a detailed submodel may be used to calculate the probability distribution for the variable from probabilities assessed on model inputs. For a screening decision we may, for example, directly estimate the number of occurrences and the severity of a given health effect. If a regulatory decision analysis is warranted, we would use a more detailed structural model, requiring specification of a number of parameters in order to calculate occurrence and severity.

Coordination of the decision stages also requires the use of a consistent decision criterion; again, it may have greater detail at the later stages.

Coordination of Decisions Regarding Different Substances

It is important that decisions regarding a wide variety of chemicals be made in a consistent and coordinated manner. Such consistency is clearly part of the legislative intent of TSCA. At the first level, the use of an explicit decision analysis methodology will provide a strong degree of consistency. The coordination will be augmented to the extent that a common integrating model (reflecting common assumptions) can be used.

At another level, coordination requires the use of a common set of parameters (those not specific to the substance under analysis) for both the structural model and the decision criterion. In the language of decision system analysis, these are "coordinating signals," which may include

- Sizes of populations that may be exposed to a class of substances.
- Market information, including demand levels, supply quantities, and prices.
- Tradeoffs between the economic, health, and environmental outcomes.
- Tradeoffs between outcomes over time.
- Probabilistic assessments of common planning scenarios, reflecting potentially important parameters outside the chemicals sector (for example, energy prices, inflation rate).

A final level at which coordination may be necessary stems from the limitations on EPA's regulatory budget. Not all substances that may warrant regulatory analysis can be given the attention merited. With an explicit decision system, it may be possible to factor in these budget limitations so that testing and regulatory priorities are set accordingly.

SUMMARY

In this chapter we have described the basic concepts of a decision analysis methodology that can be used by the EPA for toxic substances unreasonable risk determination and priority setting. The methodology is capable of treating the difficult dimensions of unreasonable risk determination: complex physical, biological, and economic interactions, numerous uncertainties, diverse impacted groups, and conflicting objectives. Key components of the methodology include structural modeling, sensitivity analysis, and explicit treatment of uncertainty. New information can be factored in as it is obtained, and the economic value of developing more information can be estimated in a consistent manner. Finally, the concepts of decision system analysis can provide a basis for priority setting and the coordination of decisions regarding a wide range of potentially toxic substances.

Section 4

REFERENCES

[1] Pesticide and Toxic Chemical News, February 17, 1982, pp. 10-11.

[2] Chemical and Engineering News, February 22, 1982, p. 27.

[3] Harold P. Green, "Legal and Political Dimensions of Risk-Benefit Methodology." In Risk-Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22-26, 1975, Asilomar, California, pp. 273-290.

[4] National Research Council, Decision Making for Regulating Chemicals in the Environment (Washington, D.C.: National Academy of Sciences, 1975).

[5] National Research Council, Decision Making in the Environmental Protection Agency, Vol. II (Washington, D.C.: National Academy of Sciences, 1977).

[6] W. W. Lowrance, Of Acceptable Risk: Science and the Determination of Safety (Los Altos, Calif.: William Kaufmann, Inc., 1976).

[7] J. Davies, S. Gussman, and F. Irwin. Determining Unreasonable Risk Under the Toxic Substances Control Act (Washington, D.C.: The Conservation Foundation, 1979).

[8] A. R. Prest and R. Turvey, "Cost-Benefit Analysis: A Survey," The Economic Journal 75 (1965).

[9] M. Hill, "A Goals-Achievement Matrix for Evaluating Alternative Plans," Journal of the American Institute of Planners 34, no. 1, (1968): 19-29.

[10] E. J. Mishan, Cost-Benefit Analysis (New York: Praeger Publishers, 1971).

[11] Toxic Substances Strategy Committee, Toxic Chemicals and Public Protection (Washington, D.C.: Council on Environmental Quality, May 1980).

[12] R. A. Howard, "The Foundations of Decision Analysis," IEEE Transactions on Systems Science and Cybernetics SSC-4, no. 3 (1968): 211-219.

[13] R. A. Howard, "Decision Analysis In Systems Engineering," Systems Concepts: Lectures on Contemporary Approaches to Systems, ed. R. F. Miles (New York: John Wiley and Sons, 1973).

[14] R. A. Howard, "Social Decision Analysis," Proceedings of the IEEE 63, no. 3 (1975): 359-371.

[15] D. W. North, "A Tutorial Introduction to Decision Theory," IEEE Transactions on Systems Science and Cybernetics SSC-4, no. 3 (1968).

[16] H. Raiffa, Decision Analysis: Introductory Lectures on Choices Under Uncertainty (Reading, Mass.: Addison-Wesley Publishing Co., 1968).

[17] D. W. North and M. W. Merkhofer," A Methodology for Analyzing Emission Control Strategies," Computers and Operations Research 3 (1976): 185-207.

[18] D. W. North and M. W. Merkhofer, "Analysis of Alternative Emissions Control Strategies." Chapter 13 in Air Quality and Stationary Source Emission Control. Report by the Commission on Natural Resources, National Academy of Sciences (Washington, D.C.: U.S. Government Printing Office, 1975).

[19] R. A. Howard, J. E. Matheson, and D. W. North, "The Decision to Seed Hurricanes," Science 176 (1972): 1191-1202.

[20] R. L. Keeney and G. A. Robilliard, "Assessing and Evaluating Environmental Impacts at Proposed Nuclear Power Plant Sites," Journal of Environmental Economics and Management 4 (1977): 153-166.

[21] National Research Council, Polychlorinated Biphenyls (Washington, D.C.: National Academy of Sciences, 1979).

[22] R. A. Howard, Life and Death Decision Analysis. Research Report No. EES DA-79-2, Department of Engineering-Economic Systems, Stanford, California, December 1979.

[23] R. D. Luce and H. Raiffa, Games and Decisions (New York: John Wiley and Sons, 1965).

[24] A. K. Sen, Collective Choice and Social Welfare (San Francisco: Holden-Day, Inc., 1970).

[25] D. W. Boyd and C. E. Clark, Jr., Multi-Party Decision Analysis for Social Decisions. Decision Focus Incorporated Working Paper No. 2, 1978.

[26] S. M. Barrager, Bruce R. Judd, and D. Warner North, The Economic and Social Costs of Coal and Nuclear Electric Generation: A Framework for Assessment and Illustrative Calculations for the Coal and Nuclear Fuel Cycles, prepared for the National Science Foundation, U.S. Government Printing Office Stock Number 038-000-00293-7, March 1976.

[27] P. A. Owen, "Decisions That Affect Outcomes in the Distant Future" (Ph.D. dissertation, Stanford University, 1979).

[28] Interagency Regulatory Liaison Group, "Scientific Bases for Identification of Potential Carcinogens and Estimation of Risks," Federal Register 44, no. 131 (1979): 39858-39879.

[29] D. R. Calkins et al., "Identification, Characterization, and Control of Potential Human Carcinogens: A Framework for Federal Decision-Making," Executive Office of the President, Office of Science and Technology Policy (1979). Also published in Journal of the National Cancer Institute 64, no. 1 (1980): 169-176.

[30] L. Slesin and R. Sandler, "Categorization of Chemicals Under the Toxic Substances Control Act," Ecology Law Quarterly 7, no. 2 (1978): 359-396.

[31] C. S. Spetzler and C.A.S. Stael von Holstein, "Probability Encoding in Decision Analysis," Management Science 22, no. 3 (1975).

[32] A. Tversky and D. Kahneman, "Availability: A Heuristic for Judging Frequency and Probability," Cognitive Psychology 5 (1973): 207-232.

[33] Judgment Under Uncertainty: Heuristics and Biases, D. Kahneman et al., ed. (Cambridge: Cambridge University Press, 1982).

[34] T. S. Wallsten and D. V. Budescu, Encoding Subjective Probabilities: A Psychological and Psychometric Review. Report prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1980.

[35] 21 U.S.C. Sec. 301.

[36] 15 U.S.C. Sec. 2605(c)(1).

[37] M. S. Baram, Regulation of Health, Safety, and Environmental Quality and the Use of Cost-Benefit Analysis. Report to the Administrative Conference of the United States, March 1979.

[38] Executive Order 12044, Sec. 3.

[39] Federal Register, Presidential Documents 46, no. 33 (1981): 13193-13198.

[40] *AFL-CIO* v. *Marshall*, No. 78-1562; *Cotton Warehouse Assn*. v. *Marshall*, No. 78-1736 (Bazelon opinion).

[41] 541 F.2d 1, 8 ERC 1785 (D.C. Cir.) (en banc), cert. denied, 426 U.S. 941, 8 ERC 2200.

[42] 514 F.2d 492 (8th Cir. 1975) (en banc).

[43] *American Textile Manufacturers* v. *Donovan*, No. 79-1429; *National Cotton Council* v. *Donavan*, No. 79-1583 (Brennan opinion).

[44] *Business Week*, July 21, 1980, pp. 65-66.

[45] P. Handler, "Some Comments on Risk Assessment," *The National Research Council in 1979: Current Issues and Studies* (Washington D.C.: National Academy of Sciences, 1979), pp. 3-24.

[46] T. Page, "A Generic View of Toxic Chemicals and Similar Risks," *Ecology Law Quarterly* 7, no. 2 (1978): 207-244.

[47] T. Page, "A Framework for Unreasonable Risk in the Toxic Substance Control Act (TSCA)," *Annals of New York Academy of Sciences* 363 (April 30, 1981): 145-166.

[48] National Research Council, *Saccharin: Technical Assessment of Risks and Benefits, Part 1* (Washington D.C.: National Academy of Sciences, 1978).

[49] J. P. Leape, "Quantitative Risk Assessment in Regulation of Environmental Carcinogens," *Harvard Environmental Law Review* 4, no. 86, pp. 86-116.

[50] W. C. Clark, "Witches, Floods, and Wonder Drugs: Historical Perspectives on Risk Management," *Proceedings of Symposium on Societal Risk Assessment: How Safe Is Safe Enough?* Richard C. Schwing and Walter A. Albers, Jr., ed. (New York: Plenum Press, 1980).

[51] T. H. Maugh, "Chemical Carcinogens: The Scientific Basis of Regulation," *Science* 201 (1978): 1200-1205.

[52] B. N. Ames, "Identifying Environmental Chemicals Causing Mutations and Cancer," *Science* 204 (1979): 587-593.

[53] Harold H. Schmeck, "Cancer Research Criticized," interview with Dr. Joshua Lederberg, *New York Times*, March 18, 1980.

[54] R. Bates, "Priority Setting for Carcinogenesis and Mutagenesis Testing: Approaches of the FDA," *Proceedings of the Second Food and Drug Administration Office of Science Summer Symposium*, Annapolis, Maryland, August 31-September 2, 1977, pp. 211-215.

[55] D. D. Doniger, "Federal Regulation of Vinyl Chloride: A Short Course in the Law and Policy of Toxic Substance Control," *Ecology Law Quarterly* 7, no. 2 (1978): 497-675.

[56] National Research Council, *Regulating Pesticides* (Washington, D.C.: National Academy of Sciences, 1980).

[57] J. Cornfield, "Carcinogenic Risk Assessment," *Science* 198 (1979): 693-699.

[58] U.S. House Committee on Interstate and Foreign Commerce, *Legislative History of the Toxic Substances Control Act* (Washington, D.C.: U.S Government Printing Office, 1976).

[59] Environmental Protection Agency, *Initial Report of the TSCA Interagency Testing Committee* (Washington, D.C.: U.S. Government Printing Office, 1978).

[60] *Systems for Rapid Ranking of Environmental Pollutants*. Report No. EPA-600/5-78-012, Environmental Protection Agency, Washington, D.C., June 1978.

[61] U.S. House of Representatives, Committee on Interstate and Foreign Commerce, *Legislative History of the Toxic Substances Control Act*, (Washington, D.C.: U.S. Government Printing Office, December 1976) p. 14.

[62] R. D. Willig, "Consumer Surplus Without Apology," *American Economic Review*, 66(4) (1976).

[63] R. A. Howard, "Information Value Theory," *IEEE Transactions on Systems Science and Cybernetics* SSC-2, no. 1 (1966), pp. 22-26.

[64] R. A. Howard, "Value of Information Lotteries," *IEEE Transactions on Systems Science and Cybernetics* SSC-3, no. 1 (1967), pp. 54-60.

[65] E. G. Cazalet, *Generalized Equilibrium Modeling: The Methodology of the SRI-Gulf Energy Model*. Final Report prepared by Decision Focus Incorporated for the Federal Energy Administration, May 1977.

[66] D. W. Boyd and E. G. Cazalet, *An Illustrative Example of the Application of Resource Allocation Using Price Iteration for Decentralization* (Menlo Park, Calif.: Stanford Research Institute, Decision Analysis Group Report, March 1971).

[67] D. W. Boyd, D. W. North, and S. G. Regulinski, *A Resource Allocation Methodology for Establishing RD&D Budgetary Priorities*. Final Report prepared by Decision Focus Incorporated for U.S. Department of Energy, February 1979.

PART II

PERCHLOROETHYLENE: A CASE STUDY OF THE APPLICATION OF DECISION ANALYSIS TO THE DETERMINATION OF THE RISK POSED BY A TOXIC CHEMICAL

Part II

CONTENTS

Section		Page
1	INTRODUCTION AND SUMMARY	1-1
2	THE DRY CLEANING INDUSTRY	2-1
3	PCE EXPOSURE CALCULATIONS	3-1
	Worker Exposure	3-2
	User Exposure	3-5
	Exposure to Urban Population	3-8
	Summary of Exposure Calculations	3-12
4	CONTROL OPTIONS	4-1
	Description of Control Options	4-2
	Determining Costs and Effects of Control Options	4-4
	Data for Control Options Analysis	4-8
	Results of Costs and Exposure Calculations	4-15
5	HEALTH EFFECTS OF PERCHLOROETHYLENE	5-1
	Toxicological Impacts of Perchloroethylene	5-1
	Carcinogenic Effects of Perchloroethylene	5-2
6	MODEL FOR DOSE RESPONSE RELATIONSHIP FOR PCE	6-1
	Scaling Method	6-2
	Species Type for Extrapolation	6-3
	Extrapolation Model	6-5
7	ANALYSIS OF CONTROL OPTIONS	7-1
	Structure of the Control Decision	7-1
	Selection of Best Control Option	7-5
	Sensitivity Analysis	7-8

CONTENTS (continued)

Section Page

8 VALUE OF FURTHER INFORMATION 8-1

9 INSIGHTS FROM THE PERCHLOROETHYLENE CASE STUDY 9-1

Insights Regarding Perchloroethylene 9-1

Insights Regarding the Methodology 9-2

10 REFERENCES 10-1

APPENDIX A: CALCULATING AN ANNUAL CAPITAL CHARGE FOR AN INVESTMENT A-1

APPENDIX B: DETAILED CALCULATIONS OF CONTROL COSTS AND EXPOSURE REDUCTION B-1

APPENDIX C: CALCULATIONS OF PROBABILITY OF INCIDENCE AND EXPECTED CANCER CASES BY CONTROL OPTION AND DOSE RESPONSE CASE C-1

Part II

FIGURES

Figure		Page
7-1	Decision Tree for PCE Control Analysis	7-2
7-2	Sensitivity Analysis on Cost per Cancer Case	7-9
8-1	Decision Tree for Calculating Value of Perfect Information on All Dose Response Uncertainties	8-2
8-2	Decision Tree for Expected Value of Perfect Information on Scaling Method	8-4
8-3	Decision Tree for Expected Value of Perfect Information on Species Type	8-5
8-4	Decision Tree for Expected Value of Perfect Information on Extrapolation Model	8-6

Part II

TABLES

Table		Page
2-1	Dry Cleaning Plants Using PCE	2-2
3-1	Exposure Levels in Commercial Dry Cleaners by Type of Worker	3-2
3-2	Exposure Levels for Machine Operators in Industrial Dry Cleaners	3-3
3-3	Number of Dry Cleaning Plants by Size of Operation	3-4
3-4	Estimated Number of Workers and PCE Exposure in Dry Cleaning Plants Using PCE	3-6
3-5	PCE Concentrations in Coin-Operated Dry Cleaners	3-8
3-6	Estimated Number of Users of and PCE Exposure from Dry Cleaning Services	3-9
3-7	Concentrations of PCE and Urban Populations at Specified Distances from Typical Dry Cleaning Point Sources	3-11
3-8	Summary of Ambient PCE Concentrations in Three Cities	3-12
3-9	Summary of Calculations of PCE Exposures from the Dry Cleaning Industry	3-13
4-1	Control Options and Combinations of Options Considered for Analysis	4-5
4-2	Summary of Control Costs and Exposure Reduction Factors by Control Option	4-16
5-1	Incidence of Hepatocellular Carcinomas in B6C3F1 Mice Fed Tetrachloroethylene	5-3
7-1	Enumeration of Dose Response Cases	7-4
7-2	Control Costs and Expected Cancer Cases	7-6
7-3	Selection of Optimal Decision	7-8
7-4	Sensitivity Analysis of Probability Assignments	7-11
8-1	Data for Calculating Expected Value of Perfect Information	8-7
8-2	Expected Value of Perfect Information on All Dose Response Uncertanties	8-7
8-3	Expected Value of Perfect Information on Each Component of Dose Response Uncertainty	8-8

Section 1

INTRODUCTION AND SUMMARY

Legislation such as the Toxic Substance Control Act (TSCA) requires regulatory agencies to make decisions on chemicals that may pose an unreasonable risk to human health and the environment. These decisions may be highly controversial, for there is little agreement on the appropriate basis for making them. The term unreasonable risk is not defined in the legislation. While many argue in favor of cost-benefit analysis, there are few examples to show how cost-benefit analysis methods can be applied to regulatory decisions on chemicals. The use of quantitative methods is criticized for lending an air of false precision to a problem area fraught with uncertainty. Others question whether cost-benefit criteria ignore important distributional issues of who receives the benefits and who bears the costs. This report provides a specific case study example that addresses some of these difficult issues.

Previous sections of this report have reviewed the literature of cost-risk-benefit analysis (Part I, Section 2) and have presented a description of decision analysis as a basis for decision making under TSCA (Part I, Section 3). This part of the report presents a case study application of decision analysis to perchloroethylene, a widely used chemical suggested by staff of the EPA Office of Toxic Substances as representative of chemicals which may be considered for regulatory decisions.

Perchloroethylene, sometimes called tetrachloroethylene and abbreviated PCE or PERC, is a solvent used for about 75 percent of the dry cleaning done in the United States. Dry cleaning accounts for about 50 percent of PCE consumption in the United States, other uses being metal cleaning, textile processing, and use as a chemical intermediate. PCE is not a new chemical, but rather one that has been in widespread use for decades. Its potential for liver damage and other acute toxicity effects in humans has been known for many years and is the basis for the current occupational standard of 100 parts per million of PCE vapor in the air. PCE has recently come under suspicion as a potential carcinogen. Its chemical structure is similar to a known human carcinogen, vinyl chloride. Short-term tests indicate that a commercial preparation of PCE is mutagenic, and there is some epidemiological evidence of higher cancer occurrence among dry cleaning workers. However, the strongest evidence implicating PCE as a carcinogen is a recent animal test carried out by the National Cancer Institute in which a sensitive strain of mouse showed a high incidence of liver tumors when fed PCE.

The Carcinogen Assessment Group (CAG) of EPA prepared a summary of the evidence for the carcinogenicity of PCE [1]. This document was subsequently reviewed by the Subcommittee on Airborne Carcinogens of the EPA Science Advisory Board in a public meeting [2]. Despite the language in the recent Interagency Regulatory Liaison Group guidelines [3] that a single positive animal test is ordinarily sufficient to establish that a chemical should be regarded as a carcinogen for regulatory purposes, the SAB subcommittee declined to endorse such a judgment for PCE.

The focus of our case study is the determination of risk for a specific chemical, perchloroethylene. We shall use the methods of decision analysis to develop a quantitative description of the cancer risk posed by PCE to workers, users of dry cleaning services, and members of the public who live or work near dry cleaning plants. We shall examine the change in cancer risk for a variety of control options that could reduce PCE emissions and human exposure. By introducing an explicit value judgment on the worth of avoiding a case of cancer, we are able to determine the best strategy in the sense of maximizing benefits less costs.

The analysis is based on data for 1978. Our impression is that the volume of dry cleaning and the alternatives and their real dollar costs associated with lowered perchloroethylene exposure have changed little over the past three years. The reader should bear in mind that the purpose of this case study is a demonstration of the methodology. The analysis is intended to be illustrative. The data are the result of a modest level of effort by the authors, making use of the sources of industry information brought to our attention by EPA.

The impact of uncertainty in this example is profound. We believe that the most effective way to assess uncertainty on the impact of PCE is not by requesting probabilistic judgments on whether PCE is a carcinogen but by examining the judgments required to extrapolate from the results of animal experiments and other available scientific evidence to a projection of the incidence of human cancer that PCE exposure may induce. Based upon our examination of the literature, in particular [1] and [2], we have identified the following factors as crucial:

- The basis for extrapolating dose in small laboratory animals to an equivalent dose in humans.
- Identification of the most appropriate laboratory animal to use as a model for cancer impacts in humans.
- The numerical basis for extrapolation of cancer incidence from high doses in laboratory animals to lower levels corresponding to human exposure.

For each factor, we have considered two alternative assumptions, giving a total of eight combinations. The effect of the alternative assumptions is great. Using conservative judgments, such as those used by CAG [1] (extrapolation based on surface area, most sensitive mouse strain as a model for man, linear nonthreshold dose response relation), the projected cancer incidence is about 350 cases per year. Under alternative, less conservative assumptions (extrapolation based on body weight, rat as the model for man, nonlinear dose response relation), the projected cancer incidence is nearly five orders of magnitude less, 0.01 cases per year. We therefore examine each combination of assumptions and develop a probability distribution over cancer incidence from probabilities assigned to the three crucial factors in the dose response relationship. The methods of decision analysis can be used to determine that it would be worth several million dollars per year to resolve this uncertainty by such means as large-scale bioassays of PCE. Such bioassays are in fact being carried out for PCE by NCI.

This part of the report is made up of nine sections. Section 2 gives an overview of the dry cleaning industry, and Section 3 presents estimates of PCE exposure based on data and analysis contained in EPA and NIOSH reports. Section 4 describes control options for reducing PCE exposures and provides estimates of the exposure reduction and associated annualized cost. Section 5 discusses the available information (taken from NIOSH and EPA sources, including the transcript of the SAB meeting [2]) on the health impacts of PCE. Section 6 describes the specific assumptions used in modeling the relation between human exposure and cancer incidence. Section 7 presents the analysis of control options. For each control option, we compute the impact in terms of expected cases of cancer and control cost. The best control option alternative is determined based on a value judgment of one million dollars per case of cancer avoided; the sensitivity of the control option choice to this judgment is explored. Section 8 gives the calculation for the value of additional information to resolve uncertainty in the relation between exposure to PCE and cancer incidence. Section 9 contains conclusions regarding PCE and the decision analysis methodology.

The scope of this case study is limited to the use of PCE as a solvent in dry cleaning and the possible health effect of increased human cancer. We have not included a discussion of human exposure from other PCE uses, other human health impacts, or adverse effects that PCE may have on the environment. This choice of scope was motivated by the perception that human cancer resulting from dry cleaning-related exposure is the major concern of EPA and other regulatory agencies.

Section 2

THE DRY CLEANING INDUSTRY

The dry cleaning industry is composed of several types of firms that use various types of equipment and solvents to clean clothing and other items made of fabric or leather. The three main types of dry cleaning firms are commercial, coin-operated, and industrial. Commercial dry cleaners are those firms engaged in cleaning and pressing consumer items such as garments and drapes. Coin-operated dry cleaners are self-service installations, usually found in coin-operated laundries. Industrial dry cleaners are those engaged in cleaning heavily soiled items such as uniforms, coveralls, and towels for industrial and commercial users.

In a report done for EPA [4], SRI estimated that in 1978 there were approximately 22,000 commercial dry cleaners, 11,000 coin-operated laundries with dry cleaning machines, and 700 industrial cleaners with dry cleaning equipment. The number of commercial dry cleaners can be taken directly from the Bureau of Census data [5]. However, because the figures for coin-operated and industrial cleaners included plants with water-based washing equipment only, the number of plants with dry cleaning equipment could only be estimated.

Solvents used in dry cleaning can be categorized into two groups: petroleum solvents and synthetic solvents. Petroleum solvents, which include Stoddard and 140F, are mixtures of hydrocarbons similar to kerosene. Synthetic solvents, such as perchloroethylene (PCE) and fluorocarbon-113, are halogenated hydrocarbons. Perchloroethylene is by far the most widely used synthetic solvent in use today. According to estimates of the International Fabricare Institute (IFI) [6], about three quarters of the commercial dry cleaners use PCE, with the other one quarter using petroleum solvents. Almost all (97 percent) of the coin-operated cleaners use PCE, with the remainder using fluorocarbon-113. About half of the industrial cleaners use PCE and half use petroleum solvents. (See Table 2-1.)

Table 2-1

DRY CLEANING PLANTS USING PCE
(1978)

Type of Operation	Number of Plants	Number Using PCE	Percent Using PCE
Commercial	22,000	16,000	74
Industrial	700	350	50
Coin-Operated	11,000	11,000	97

The main advantage of the synthetic solvents is that they are non-flammable, unlike the petroleum solvents, which are highly flammable. The major disadvantage is the cost. PCE costs about three times and fluorocarbon-113 costs about ten times as much per gallon as petroleum solvents. Because of the cost, the synthetic solvents must be recycled for economic operation. The efficiency of the recycling equipment largely determines both the cost to the dry cleaner and the exposure of workers and others to PCE.

Dry cleaning equipment consists of cleaning machines and equipment for recovering and purifying used solvents. In all types of cleaning machines, there are three cycles, much like the cycles of regular water laundry. The three cycles are washing, in which solvent is mixed with clothing in a rotating drum; spinning, in which solvent is extracted by centrifugal force; and drying, in which the clothes are rotated in warm air.

The two main types of cleaning machines are transfer units and dry-to-dry units. In transfer units, the washing and extraction are done in one machine. Then the clothes, still damp with solvent, are transferred by hand to a separate dryer. In a dry-to-dry unit, all three cycles are accomplished in the same machine: the clothes are put in dry and taken out dry. The dry-to-dry units eliminate the need for the operator to handle solvent-laden clothing. However, to clean the same volume of garments, the dry-to-dry unit must have a larger capacity than the corresponding transfer unit, since the separate washer and dryer can be operated simultaneously. Currently, about 80 percent of commercial and virtually all industrial dry cleaners have transfer units, although there seems to be a trend toward installing dry-to-dry units [7]. Virtually all coin-operated dry cleaning units are dry-to-dry [8].

Solvent recovery and recycling equipment consists of filters, distillers, and adsorbers. All plants have some equipment for filtering and distilling used solvent to remove dirt and water. There are several types of filters, including single-charge tube type and multicharge filters, which use a powder such as diatomaceous earth. If a single-charge filter is used, the distiller can operate at room temperature, since the PCE is highly volatile compared to water. However, most plants that use a powder type of filter have a combination cooker and still designed to remove PCE from the filter residue or "muck."

About half of the commercial dry cleaners have a carbon adsorption unit in addition to a filter and still [8]. These units, which are also called "sniffers," remove PCE vapors from the air in the work area. They can both reduce cost by recovering solvent and reduce PCE exposure.

In all of the equipment just described, including the cleaning machines and the solvent recovery systems, maintenance is extremely important for low solvent emissions. Leaky gaskets and clogged filters can result in large PCE losses. Therefore, good maintenance can minimize solvent cost as well as exposure resulting from emissions. A recent EPA report [8] contains an excellent discussion of cleaning equipment, solvent recovery systems, and maintenance procedures.

Section 3

PCE EXPOSURE CALCULATIONS

Because of the widespread use of PCE in dry cleaning, many people are potentially exposed. To estimate the extent of the exposure, three classes of people are considered:

1. Workers in the dry cleaning industry.
2. People who use dry cleaning services.
3. People who live or work near dry cleaning facilities.

Inhalation of vapors is the primary route of exposure to PCE. Absorption through the skin is not considered to be significant [1]. Following the procedures of EPA [9] and NIOSH [10], the method of determining exposure to PCE consists of estimating the average exposure to each category of people under consideration and then estimating the number of people in each category. The base year of 1978 is chosen for the analysis to be consistent with the industry data discussed in Section 2.

Exposure to workers and users of dry cleaning services is estimated from measured air samples in dry cleaning facilities and from assumptions concerning the amount of time spent in the facilities. Additional exposure to service users from PCE vapors from freshly cleaned clothing is also estimated. An annual average exposure level is then calculated from the following formula [11]:

$$\text{Average Annual Exposure} = \frac{\text{(Exposure Level)(Hours of Exposure Per Year)}}{\text{8760 Hours Per Year}} \qquad (3.1)$$

For example, workers are assumed to work 40 hours per week and 50 weeks per year, or 2000 hours. Therefore, their average annual exposure is computed to be the average exposure during work multiplied by 2000/8760. In this case study, we use the average annual PCE exposure to workers to estimate the expected number of annual cancer cases. It would also be possible to consider the average number of years worked in a lifetime to calculate an average lifetime exposure. The use of average annual exposure gives somewhat higher cancer incidence estimates than would average lifetime exposure.

The number of workers employed in each type of dry cleaning firm is estimated from U.S. Bureau of Census data [5] as summarized in [4]. The number of users of dry cleaning services is estimated from the volume of dry cleaning business and from estimates of the average number of cleaning loads per user per year [11].

The exposure to urban residents is calculated from a simplified Gaussian dispersion model for airborne pollution by PCE [11]. Dry cleaning facilities are modeled as point sources evenly distributed over urban areas. The annual average PCE concentration is calculated for concentric areas around each source, and the number of people living in each area is calculated from the average population density of urban areas.

WORKER EXPOSURE

Exposure Levels

In a survey of 44 commercial dry cleaners, NIOSH [10] measured concentrations of PCE as shown in Table 3-1. In that study, the average exposure to dry cleaning machine operators was found to be 31 parts per

Table 3-1

EXPOSURE LEVELS IN COMMERCIAL DRY CLEANERS BY TYPE OF WORKER

Job Description	Concentration of PCE (ppm) Range	 Mean
Machine Operator	4.0 - 149	31.0
Presser	0.1 - 37	5.9
Seamstress	0.6 - 29	6.6
Counter Worker	0.3 - 26	5.9

Source: NIOSH [10]

million (ppm), and the exposures at different plants ranged from 4 to 149 ppm. Exposure to other workers, such as pressers, seamstresses, and counter workers, was found to vary from 0.1 to 37 ppm, with an average of about 6 ppm. Clearly, with such a wide range of exposures, the average (mean) value does not fully describe the exposure to workers. However, for our analysis, the total number of workers will be divided into two groups defined by different exposure levels: machine operators and all other workers. The workers in each of the two groups are assumed to be exposed to the average level for that group.

To calculate potential health effects of exposures to PCE, it is convenient to express the concentrations in units of micrograms per cubic meter ($\mu g/m^3$) rather than in parts per million. For PCE, the factor for converting ppm to $\mu g/m^3$ is 6.7×10^3. Therefore, the average PCE concentration in the workplace for machine operators is taken to be $31 \times 6.7 \times 10^3$, or 200×10^3 $\mu g/m^3$, and for other workers $6 \times 6.7 \times 10^3$, or 40×10^3 $\mu g/m^3$. To express these concentrations as average annual exposures, we use equation (3.1), which implies multiplying the above concentrations by 2000/8760. The resulting average annual exposures are thus approximately 45×10^3 $\mu g/m^3$ for machine operators and 10×10^3 $\mu g/m^3$ for other workers.

Exposure data for industrial and coin-operated dry cleaners are available but are not so extensive as data for commercial cleaners. In an assessment of engineering controls done for NIOSH [12], exposures to machine operators were measured in three industrial dry cleaners that use PCE. (See Table 3-2.) From these samples, there appears to be almost no

Table 3-2

EXPOSURE LEVELS FOR MACHINE OPERATORS IN INDUSTRIAL DRY CLEANERS

Case Study Number	Range of PCE Exposure (ppm)
2	25 - 30
13	13 - 40
17	30 - 35

Source: Reference [12]

111

difference in exposures between industrial and commercial cleaners. We therefore assume the same levels, that is, 31 ppm for machine operators and 6 ppm for other workers. These concentrations are then converted to the same average annual exposure levels (i.e., 45×10^3 $\mu g/m^3$ for machine operators and 10×10^3 $\mu g/m^3$ for other workers in industrial plants).

In an EPA survey [13] of a single combination laundry and cleaner in Raleigh, North Carolina, the exposure to an operator/maintenance person was found to be 4.4 ppm. In the following analysis, we assume all workers in coin-operated cleaners are exposed to about 4 ppm of PCE, which is equivalent to an average annual exposure of 6×10^3 $\mu g/m^3$.

Number of Workers in Each Exposure Category

Once exposure levels have been determined, the second part of the assessment of worker exposure is to estimate the number of workers in each category. The numbers of workers in commercial, industrial, and coin-operated cleaners are estimated from the data in [4]. These data give the number of dry cleaning firms in the United States by the number of employees in each firm. (See Table 3-3.) Although the details of these data are not discussed in [4], the data appear to represent only a fraction of all dry cleaning establishments. Since the number of plants is significantly smaller than in Table 2-1, we assume that this sample is representative of the entire industry.

Table 3-3

NUMBER OF DRY CLEANING PLANTS BY SIZE OF OPERATION

	Number of Plants		
Number of Employees	Commercial	Industrial	Coin-Op
1 - 4	4194	16	3695
5 - 9	1906	11	499
10 - 19	846	18	119
20 - 49	691	98	57
50 +	119	112	12

Source: Reference [4]

To calculate the average number of employees per type of firm, we assume the following average value for each of the ranges for the number of employees:

Range	Assumed Average
1 - 4	2
5 - 9	7
10 - 19	14
20 - 49	30
50 +	100

Multiplying these assumed averages by number of plants in each size range, the average number of workers is computed to be eight per commercial plant, sixty per industrial plant, and three per coin-operated plant. Based on the typical plants described in [10] and [12], we assume that for commercial plants about one out of eight workers is a machine operator, for industrial plants about two out of sixty workers are machine operators, and for coin-operated plants about one out of three workers is a machine operator. In industrial plants, many of the workers are involved with laundry rather than with dry cleaning. However, because the laundry and dry cleaning equipment is usually located in the same building, these workers are exposed to PCE. Multiplying these estimates by the estimated number of plants using PCE gives an estimate of the total number of workers. These estimates, together with the previously described exposure estimates, are given in Table 3-4.

USER EXPOSURE

Three types of users of dry cleaning services are considered in this analysis:

1. Users of commercial dry cleaners.
2. Users of coin-operated dry cleaners.
3. Users of coin-operated laundries located in facilities with coin-operated dry cleaning machines.

Table 3-4

ESTIMATED NUMBER OF WORKERS AND PCE EXPOSURE
IN DRY CLEANING PLANTS USING PCE

Worker Category	Number of Workers	Average Annual PCE Exposure Level ($\mu g/m^3$)
Machine Operators		
Commercial	16,000	45,000
Industrial	700	45,000
Coin-Op	11,000	6,000
Other Workers		
Commercial	110,000	10,000
Industrial	20,000	10,000
Coin-Op	22,000	6,000

Users of industrial dry cleaners were not considered because of their relatively small numbers, although the exposures may be comparable to the above groups. PCE exposure to users of dry cleaning services in categories 1 and 2 is assumed to come from two sources: visiting cleaning establishments and having dry cleaned clothing at home. Exposure to people in category 3 is assumed to arise from visits to laundries with dry cleaning machines. These people are exposed to PCE even though they do not directly use dry cleaning services.

Exposure from Visits to Cleaners

The method for estimating exposure from visits to dry cleaners involves estimating the total number of cleaning loads per year in the United States and dividing this total into the expected number of users and the average number of loads per user per year. Exposure times corresponding to cleaning loads are estimated, and the exposure levels are taken from measurements similar to those used in determining worker exposure.

The annual volume of commercial dry cleaning is about two billion pounds [8,10]. Assuming an average of 5 pounds per average single load implies a total of 400 million loads per year, and assuming an average of 8 loads per user per year results in an estimate of 50 million users. Of course some users will make more and some will make fewer than eight visits. However, these numbers appear to be representative. To estimate user exposure, we assume an average of one load per visit to a dry cleaner at five minutes per visit at an exposure of six ppm, which corresponds to the average measured concentration at the counter area [10].

Data for estimating the number of loads of cleaning in coin-operated laundries come from the National Automatic Laundry Cleaning Council as reported by Mara [11]. According to these data, the gross income from coin-operated washing is one billion dollars at an average cost of $0.50 per load, while the gross income from coin-operated dry cleaning is $400 million at an average cost of $4.00 per load. Therefore, approximately 2 billion loads are washed and 100 million loads are dry cleaned at coin-operated laundromats. Assuming an average of two loads per trip and twenty trips per year implies about 50 million users of coin-operated laundries, and assuming one load per trip and four trips per year implies about 25 million users of coin-operated dry cleaning. According to SRI estimates [4], about 75 percent of the laundromats in the United States also have coin-operated dry cleaners, almost all of which use PCE. Therefore, assuming that about 75 percent of all laundromat users are exposed to PCE implies that 75 percent of 50 million, or 37 million, laundromat users are exposed to PCE.

To estimate exposure to users of coin-operated dry cleaning machines, we use the average of the PCE concentration measurements summarized in Table 3-5. We assume one load per visit to the cleaner at 30 minutes per visit at a PCE concentration of 5 ppm, which is an approximate average of concentrations near the dry cleaning machines. For laundromat users, we assume one hour per trip at a PCE concentration of 2.5 ppm.

Exposure from Cleaned Clothing

In an experiment to measure PCE exposure from cleaned clothing, PEDCO Environmental [14,15] placed three loads of clothing cleaned by an attendant in a coin-operated dry cleaner in a bedroom closet. After seven days

Table 3-5

PCE CONCENTRATIONS IN COIN-OPERATED DRY CLEANERS

Source		PCE Concentration (ppm) Nearest Dry Cleaning Machines	Average of Other Locations
Howie [14]	Site B	0.4	0.3
	Site C	1.5	1.2
	Site D	3.0	0.6
	Site E	9.6	8.0
	Site F	1.6	1.1
Bumgarner [13]		16.6	4.7
Average		5.5	2.7

of monitoring PCE concentration at the closet door and two locations in the room, they found concentrations of about 100 parts per billion (ppb) for one day and about 20 ppb for an additional four to five days.

For our analysis, we assume that three loads of cleaning would cause about three times the concentration of a single load. In the absence of data concerning emissions from clothes cleaned by a commercial dry cleaner, we have assumed that the PCE concentration caused by a single load would be about half that caused by a load cleaned in a coin-op since clothes usually remain longer after being cleaned in a commercial cleaner and are thus presumably drier. For exposure time, we assume that one person is exposed for 10 hours per day over a six-day period in which PCE vapors are present. The assumed exposure per cleaning load is thus 10 hours at 33 ppb for a coin-op load or 17 ppb for a commercial load and 50 hours at 6.7 ppb for a coin-op load or 3.3 ppb for a commercial load.

Converting the above concentrations to $\mu g/m^3$ and calculating average annual exposure with (3.1) for visits to the cleaners and from cleaned clothing gives the estimates shown in Table 3-6.

EXPOSURE TO URBAN POPULATION

The PCE exposure from air pollution to the general population is estimated using a general point source dispersion model as described in [9]

Table 3-6

ESTIMATED NUMBER OF USERS OF AND PCE EXPOSURE FROM DRY CLEANING SERVICES

Type of Service	Number of Users	Average Annual Exposure ($\mu g/m^3$) Visits to Cleaners	Cleaned Clothing	Total
Commercial Dry Cleaning	50 million	3	2	5
Coin-Op Dry Cleaning	25 million	8	2	10
Coin-Op Laundry	37 million	38	-	38

and [4]. The results of the model are checked against actual measurements of ambient levels to verify that the results are reasonable. To estimate the number of people exposed, we use the average population density for urban areas, including urban fringe as reported in [14]. We assume that small towns in rural areas that may have dry cleaners have roughly the same population density as this urban area. In the analysis, we consider people who live near dry cleaning facilities and assume 24 hour per day exposure. This is a simplification since people who live in one location usually work in another. A more detailed analysis might consider residents and non-dry-cleaning workers separately.

Since there are a large number of dry cleaning firms in the United States and their locations are not known, it is impractical to estimate emissions and resultant exposures originating from each individual firm. With the general point source methodology, exposure from a typical plant in a typical area is considered. Then the total U.S. exposure is calculated by multiplying by the number of dry cleaning plants.

Considering a single point source of PCE with an average emission rate of E grams/second, the average annual concentration C in $\mu g/m^3$ at a distance D from the source in km is given by [4]

$$C = 0.659 \, E \, D^{-1.48} \tag{3.2}$$

This dispersion formula was developed by regression analysis to represent dispersion from three source categories: ground level (zero meter), building level (10 meters), and stock level (20 meters). The meteorological conditions assumed were wind speed equals 4 meters per second and neutral stability class (Pasquill-Gifford "D") [16].

117

The concentration calculated from (3.2) is greatest near the source and decreases as one moves away from the source. To calculate the range of exposures in urban areas, we consider concentric rings about the point source. We assume that nobody lives within a 25-meter circle of a dry cleaner. Starting at 25 meters, we consider areas from 25 to 200 meters, 200 to 500 meters, and 500 to 1000 meters. Using (3.2) and the formulas for the circumference and area of a circle, the average concentration in a ring of inside radius R_1 and outside radius R_2 can be found from the formula

$$\text{Average Concentration} = 2.53\ E\ \frac{(R_2^{.52} - R_1^{.52})}{(R_2^2 - R_1^2)} \qquad (3.3)$$

The average emission rate E can be calculated from the estimate of total PCE consumption in dry cleaning and by the number of dry cleaning firms. It is estimated that almost all of the PCE consumed is emitted [4], and the remaining is discarded either as liquid or solid waste. From [4], the estimated consumption of PCE in dry cleaning in 1978 was 160 million kg. With 27,350 sources (the total of commercial, industrial, and coin-operated facilities), this implies an average source emission of 5900 kg per year, or 0.19 g/s.

To calculate the average number of people who live in each ring about a typical source, it is necessary to estimate the average population density of urban areas. From Census Bureau data [14], the U.S. urban population in 1970 was 149 million and the urban area was 140,000 km^2, for an average urban population density of 1004 persons/km^2. The total population in 1978 was 218 million compared to 203 million in 1970, which is a 7.4 percent increase. If we assume that the urban population increased at this same rate and that urban area increased at half that rate, or 3.7 percent, the 1978 urban population would be 160 million and the urban area 145,000 km^2. The implied population density is thus 1100 persons per km^2 in 1978. The number of people in a ring of inside radius R_1 and outside radius R_2 is given by the formula

$$\text{Avg. No. of People in Ring} = 1100\ \Pi\ (R_2^2 - R_1^2) \qquad (3.4)$$

The concentrations in each ring about a source calculated by equation (3.3) and the average number of people who live in each ring as calculated by equation (3.4) are listed in Table 3-7.

It is fairly difficult to check the estimates of the above dispersion model with measurements of ambient levels of PCE because the detection limit for PCE is about 0.1 parts per billion (ppb), which is 0.67 $\mu g/m^3$. However, the upper end of the concentration scale can be checked. In a recent study, EPA [14] measured ambient levels in three cities suspected of having unusually high PCE concentrations: New York, Detroit, and Houston. New York is a center for clothing manufacturing and has a large number of dry cleaning facilities; Houston has a major PCE production facility; and Detroit has a large number of metal cleaning operations, many of which use PCE. The 24-hour average concentrations of PCE found at each sample site are summarized in Table 3-8. New York appears to have PCE concentrations significantly above those predicted by the dispersion model that we have used; the measurements in the other cities appear to be more consistent. Recall that we are considering only emissions from dry cleaning, not from metal cleaning or PCE production. Since dry cleaning accounts for about half the total PCE consumption, one would expect that the results of the dispersion model would be about half the measured PCE concentrations.

In the exposure analysis we shall omit the background due to sources other than dry cleaning. These exposures appear to be negligible compared to the exposures received by dry cleaning workers, service users, and people living or working within 200 meters of dry cleaning plants. Even in

Table 3-7

CONCENTRATIONS OF PCE AND URBAN POPULATIONS AT SPECIFIED DISTANCES FROM TYPICAL DRY CLEANING POINT SOURCES

Distance From Source (meters)	Number of People	Average PCE Concentrations ($\mu g/m^3$)
25 - 200	3.7 million	3.5
200 - 500	20.0 million	0.6
500 - 1000	71.0 million	0.2

Table 3-8

SUMMARY OF AMBIENT PCE CONCENTRATIONS IN THREE CITIES

City	Number of Samples	Concentration (ppb) Min	Max	Median	Concentration ($\mu g/m^3$) Min	Max	Median
New York	95	0.16	10.61	1.00	1.07	71.1	6.70
Houston	96	<0.10	4.52	0.11	<0.67	30.3	0.74
Detroit	100	<0.10	2.16	0.35	<0.67	14.5	2.40

Source: EPA [14]

the case of a linear dose response curve, our analysis shows that the health impacts are expected to occur mostly in the classes of people listed above rather than urban residents or workers located more than 200 meters from the dry cleaning plants. In the case of a nonlinear dose response curve, the importance of low dose exposure to urban populations is reduced even further.

SUMMARY OF EXPOSURE CALCULATIONS

Table 3-9 is a summary of the exposure calculations. Average concentrations are converted to average daily dose by assuming an inhalation rate of 20 m^3 per day, a body weight of 70 kg, and 50 percent adsorption. Note that workers, particulary dry cleaning machine operators, are exposed to the greatest concentrations. There are many more service users, but they are exposed to much lower concentrations. Urban residents within 200 meters of a dry cleaner are exposed to levels comparable to commercial dry cleaning service users. Urban residents at a distance greater than 200 meters are exposed to about one-fifth to one-twentieth of the level inside 200 meters. The implications of these exposure levels will be explored in Section 7.

Table 3-9

SUMMARY OF CALCULATIONS OF PCE EXPOSURES FROM THE DRY CLEANING INDUSTRY

Type of Person	Numbers in U.S. Population	Average Annual Exposure ($\mu g/m^3$)	Average Annual Exposure (mg/kg/day)
Workers			
Machine Operators			
Commercial	16,000	45,000	6.43
Industrial	700	45,000	6.43
Coin-Op	11,000	6,000	0.86
Other Workers			
Commercial	110,000	10,000	1.43
Industrial	20,000	10,000	1.43
Coin-Op	22,000	6,000	0.86
Service Users			
Commercial Dry Cleaning	50,000,000	5	7.1×10^{-4}
Coin-Op Dry Cleaning	25,000,000	10	1.4×10^{-3}
Coin-Op Laundry	37,000,000	38	5.4×10^{-3}
Urban Residents (distance from dry cleaners in meters)			
25 - 200	3,700,000	3.5	5.0×10^{-4}
200 - 500	20,000,000	0.6	8.6×10^{-5}
500 - 1000	71,000,000	0.2	2.9×10^{-5}

Section 4

CONTROL OPTIONS

In this section we consider control options available to reduce human PCE exposure. Since our case study concentrates on the dry cleaning industry, each control option should be expected to reduce exposures to one or more of the groups of people identified in Section 3. The implementation of the option generally has a cost that must then be weighed against the value of the exposure reduction. The cost-benefit tradeoff is discussed in Section 7.

This section presents six control option alternatives and the estimated effect of each alternative on PCE exposures and the costs associated with its implementation. The analysis is based on prices and exposure levels as of 1978. The exposures estimated in Section 3 are considered the base case for which costs and exposure changes are compared.

While most applications of cost-benefit analysis examine control options from the viewpoint of the government agency, we have chosen to examine the decisions on control options from the point of the dry cleaning industry. We shall compute the cost of a control option, including tax effects, as it would be perceived by the individual dry cleaning plant owners. The results obtained in Section 3 indicate that benefits of reduced PCE exposure will accrue largely to the workers in the dry cleaning plants, and often the workers are in fact the owners and their immediate families. We have therefore formulated our analysis by assuming the decision makers to be private entrepreneurs who are willing to spend money to protect the health of workers (perhaps including themselves and their family) and members of the general public.

A more general approach would involve a multiparty formulation in which costs incurred for equipment purchase and operation, changes in government tax revenue, and health benefits to workers, customers, and members of the public would be separately assessed over time as the basis for decisions both by public agencies and private sector entrepreneurs. While taxes may be regarded as transfer payment by public agencies, they represent a real cost of doing business to a private sector enterprise. Moreover, tax credits or tax incentives can be an important mechanism for motivating private sector decision making to accomplish public goals such as protection of health and the environment. In this analysis we have not used the general multiparty formulation in assessing costs, but we do show which segment of the population receives the benefits. The assessment of cost including taxes is the appropriate basis for decisions by an individual dry cleaner.

DESCRIPTION OF CONTROL OPTIONS

Most of the control options considered here are discussed in the EPA study of dry cleaning performance standards [8]. All of the options are aimed at either reducing PCE emissions, which would in turn reduce exposure, or reducing exposure directly through changes in equipment or the physical layout of cleaning establishments. Options such as banning segments of the industry or banning the use of PCE were not considered.

The control options in approximate order of increasing cost are as follows:

1. Implement better maintenance and housekeeping procedures in all commercial and industrial dry cleaning establishments.
2. Implement better maintenance and housekeeping procedures in all coin-operated dry cleaning establishments.
3. Install carbon adsorption units in all commercial and industrial dry cleaning plants that do not currently have them.
4. Install carbon adsorption units in all coin-operated dry cleaners that do not already have them.
5. Replace all transfer type of cleaning machines with dry-to-dry units in all commercial dry cleaning plants when the cleaning machine normally needs to be replaced.
6. Move all coin-operated dry cleaning machines to rooms separate from the coin-operated laundry facilities.

Better maintenance and housekeeping procedures, including record keeping of PCE consumption, was identified in [8] to be one of the most effective means of reducing PCE emissions at little or no additional cost to dry cleaners. As indicated in the next section, experiments at IFI and by equipment manufacturers indicate that better maintenance can reduce PCE consumption in both transfer and dry-to-dry cleaning machines to levels substantially below the current industry average.

A somewhat more costly but still effective means of reducing PCE consumption is the addition of a carbon adsorption unit or "sniffer" to plants that do not already have one. This involves a capital investment by the dry cleaner but can actually save money in the long run due to the reduction of PCE consumption and thus can lower the cost of buying solvent. As we show in the following sections, the costs and PCE savings are less advantageous for coin-operated facilities than for commercial or industrial cleaners. However, the addition of a carbon adsorption unit in a coin-operated cleaner could reduce PCE exposure to employees and customers.

Data for calculating the costs and effects of replacing transfer units by dry-to-dry units in commercial dry cleaners are contained in [8] and [10]. It is generally believed that with equally good maintenance, dry-to-dry units would have lower PCE consumption than transfer units, since they are completely enclosed systems. However, there is little data to support this contention [8]. In fact, the five plants with dry-to-dry units monitored by Ludwig [10] had slightly higher PCE consumption than the plants with transfer units, even though the PCE exposure to workers was lower for those five plants. The approach taken in this analysis is to assume that transfer and dry-to-dry machines have the same rate of PCE consumption, but that exposure to machine operators is reduced with dry-to-dry machines by eliminating the necessity to handle solvent-laden clothing.

Finally, the last option, that of placing coin-operated cleaning machines in rooms separate from coin-operated laundry is motivated by the relatively high exposure to laundry users as estimated in Section 3. If PCE at these exposure levels is harmful, then it seems reasonable to protect those customers who are not even using the service from that exposure. Such a change in arrangement of the cleaning facility would probably require a remodelling expense and some additional floor space to make room for additional partitions and doors.

The above control options can be analyzed separately or in combination. For example, the combination of options 1, 2, and 3 (better maintenance in commercial, industrial, and coin-operated cleaners, plus the installation of carbon adsorption units in commercial and industrial plants) might be an appropriate combination of options to consider. A complete list of options and combinations of options considered in our analysis is shown in Table 4-1.

DETERMINING COSTS AND EFFECTS OF CONTROL OPTIONS

In the following analysis, control costs are considered to be the additional annual expenses associated with the control as compared with the base case (existing levels of expenses). These expenses are small compared to the total cost of providing the dry cleaning services, and they would normally be passed on from dry cleaners to consumers. Assuming that the resulting change in the amount of dry cleaning purchased by consumers is small, the impact on consumers is that they are paying more for the same service. This amount can be considered what society is paying for the exposure reductions brought about by the control.* We have not included costs that the government might incur in implementing these control options. Adding in these costs would account more fully for the total costs to society.

Control costs are considered to have three components: capital expenditures, increases in operating costs for maintenance and supplies, and credit for reduction in PCE use. The capital expenditures are required for the purchase of PCE control equipment and remodeling of dry cleaning facilities. To add capital expenditures to recurring annual costs, the capital expenditures are annualized by a formula that takes into account the return on the investment, corporate income tax, investment tax credits,

---

*If the demand for dry cleaning services decreased substantially with an increase in price resulting from a PCE control option, then the relevant measure of cost to society would be the reduction in consumer surplus. See the DEHP case study, Part III of this report, for a discussion of consumer surplus.

Table 4-1

CONTROL OPTIONS AND COMBINATIONS OF OPTIONS CONSIDERED FOR ANALYSIS

Option Number	Description
1	Implement better maintenance and housekeeping in all existing commercial and industrial plants.
2	Implement better maintenance and housekeeping in all coin-operated dry cleaners.
3	Install carbon adsorption units on all commercial and industrial plants that do not currently have them.
4	Install carbon adsorption units on all coin-operated dry cleaners that do not currently have them.
5	Replace all transfer units in commercial plants with dry-to-dry units.
6	Move all coin-operated dry cleaning machines to separate rooms from laundry.
7	Options 1 and 2.
8	Options 1, 2, and 3.
9	Options 1, 2, 3, and 4.
10	Options 1, 2, 3, and 5.
11	Options 1, 2, 3, and 6.
12	Options 1, 2, 3, 4, and 5.
13	Options 1, 2, 3, 4, and 6.
14	Options 1, 2, 3, 5, and 6.
15	Options 1, 2, 3, 4, 5, and 6.

inflation, and the tax and book life of the investment. (See Appendix A.) The result is the equivalent annual charge for the capital expenditure.

Increases in operating costs might result from increases in labor and repair parts to achieve high levels of maintenance. Additional equipment will also require maintenance, which will be a recurring expense.

The credit for reduction in PCE use is the estimated annual savings in PCE purchases resulting from the control measure if the control measure reduces PCE consumption. This credit is calculated for a typical plant by subtracting the annual PCE consumption, in gallons, after the control from the consumption before the control and multiplying by the price per gallon of PCE.

The effects of the options on PCE exposures are estimated along with the cost of the control options. There are two types of controls; each is treated somewhat differently. The first type includes options 1 through 4, which are directed primarily at reducing PCE consumption in the cleaning process. Since most of the PCE consumed is emitted in the vicinity of the dry cleaning machines, PCE consumption should be related to PCE concentration in the facility. We assume that a reduction in PCE consumption causes a proportionate reduction in PCE concentration. For example, if PCE consumption in a typical cleaner is cut in half, the average PCE concentration is assumed to be cut in half. Furthermore, the workers in that type of plant and the users of services who visit that plant are assumed to be exposed to half the base case dose of PCE. This type of control also reduces PCE emissions to the environment and thus reduces exposure to the urban population. In the model for PCE concentration near dry cleaners (equation (3.2) of Section 3), the concentration is proportional to E, the average emission rate. We therefore assume that a reduction in the total PCE emissions for all types of cleaners results in a proportionate decrease in exposure to urban residents. For example, if in the base case, half the total PCE were consumed by commercial dry cleaners, and after the control, consumption by commercial cleaners were cut in half, total PCE consumption would be three fourths of the base case. Thus, the exposure to the urban population would be cut to three fourths of the base case levels.

Exposure to users of dry cleaning services through possession of cleaned clothing is handled as a special case. We assume that through better operating procedures, commercial dry cleaners could reduce the amount of PCE left in the clothing and the resulting exposure by 50 percent. Since coin-operated cleaners have less control over the actual cleaning, we assume that better maintenance would reduce the exposure from cleaned clothing by only 25 percent.

The other type of control, which includes options 5 and 6, is assumed to act directly on PCE exposure without changing PCE consumption. For option 5 (replacing transfer type of dry cleaning machines with dry-to-dry units in commercial dry cleaners), it is assumed that PCE consumption remains the same but exposure to the machine operators is reduced. For option 6 (moving coin-operated cleaning machines to a separate room), it is assumed that PCE consumption, exposure to workers, and exposure to users of the dry cleaning machines remains the same, but exposure to users of the coin-operated laundry machines is reduced. In each case, since PCE consumption does not change, the exposure to urban population does not change.

For combinations of options, the capital costs and increases in maintenance costs of the individual options are simply added together. However, PCE consumption and the resulting exposure levels are calculated from the cumulative effect of all the options. Assume for example, that better maintenance in a particular type of plant would result in PCE consumption of 60 percent of the base case. Also assume that the addition of a carbon adsorption unit by itself would reduce PCE consumption to 70 percent of the base case. Then, it is assumed that in combination, the carbon adsorber would reduce PCE consumption to 70 percent of the level achieved after good maintenance. Therefore, after the combination, PCE consumption would be 0.6 x 0.7, or 0.42 times the base case. The PCE credit for operating cost and the exposure to workers, users, and urban population would thus be based on PCE consumption of 42 percent of the base case.

Finally, to calculate PCE consumption, it is useful to change the form of the data that are contained in most industry sources. In the dry cleaning trade, PCE consumption is expressed in pounds of cleaning per 55-gallon drum of PCE, which is called the "mileage" of the cleaning process. A typical mileage might be 6,000 pounds of cleaning per drum of PCE. Mileage can be converted to a consumption rate, expressed in pounds (or kg) of PCE consumed per pound (or kg) of cleaning, by dividing the weight of a drum of PCE (715 pounds) by the mileage as given by equation (4.1).

$$\text{Consumption Rate} = \frac{715}{\text{mileage}} \tag{4.1}$$

The total PCE consumption of a sector of the dry cleaning industry can then be calculated by multiplying the average consumption rate of that sector by the total volume of cleaning done by that sector.

DATA FOR CONTROL OPTIONS ANALYSIS

This section presents the data and assumptions used in the analysis of the control options along with a description of their sources.

PCE consumption rates are obviously a key data element. In the EPA performance standards report [8], the authors concluded that the mileage obtained in PCE plants appeared to be more strongly affected by the competence of the operator than by any other factor. The following evidence, as quoted from that report, was used to support that conclusion:

> Mileage data collected by Dow Chemical--a major perc manufacturer--in a customer survey indicate that the average perc plant without an adsorber achieves a mileage of 6,940 pounds per drum, and an adsorber increases this figure to about 8,370 pounds per drum. However, in both adsorber-equipped plants and non-adsorber-equipped plants, the range of mileages reported was enormous, and plants in each category showed both operators with mileages less than 2,000 pounds per drum and others with mileages greater than 15,000 pounds per drum.
>
> The International Fabricare Institute (IFI) gives most of the credit for either poor mileage performance or exceptional mileage performance to the plant operator. One plant (without an adsorber) visited had a mileage of 2,900 pounds per drum. The plant showed obvious mechanical problems which even superficial maintenance should have corrected. In marked contrast, IFI personnel have obtained mileages of 11,000 pounds per drum in transfer machines, without adsorbers. ([8] p. 4-9)

Combining the above data with their own plant visits, the authors of [8] used the following estimates of plant mileages in their analysis:

- Average Mileage of Commercial Plants

--uncontrolled plant	6,000 lb/drum
--housekeeping procedures	10,000 lb/drum
--housekeeping plus adsorber	15,000 lb/drum

- Average Mileage of Industrial Plants

--uncontrolled plant	10,000 lb/drum
--housekeeping procedures	15,000 lb/drum
--housekeeping plus adsorber	20,000 lb/drum

- Average Mileage of Coin-Operated Plants

--uncontrolled plant	4,400 lb/drum
--housekeeping procedures	8,000 lb/drum
--housekeeping plus adsorber	12,000 lb/drum

We also use these data with the following interpretations: The mileage for uncontrolled plants of each type is assumed to represent the current average mileage of plants without carbon adsorbers. If all cleaners in each category currently without adsorbers were able to implement the improved maintenance and housekeeping procedures, the average mileage for those plants would increase to the next higher level. For plants that currently have adsorbers, their mileage is calculated from the uncontrolled rate by assuming a reduction in consumption rate equal to the reduction obtained by adding an adsorber to a plant with good housekeeping procedures. To illustrate this calculation, note that through equation (4.1), the following mileages and consumption rates are equivalent:

Mileage	Consumption Rate
4,400	0.163
6,000	0.119
8,000	0.089
10,000	0.072
12,000	0.060
15,000	0.048
20,000	0.036

Adding a carbon adsorber to a plant with good maintenance reduces the consumption rate as shown in the following table:

	Consumption Rate Without Adsorber	With Adsorber	Ratio: Rate With/Rate Without
o Commercial	0.072	0.048	0.67
o Industrial	0.048	0.036	0.75
o Coin-Operated	0.089	0.060	0.67

The current average consumption rates for dry cleaning plants with carbon adsorbers are thus taken to be

- o Commercial 0.119 x 0.67 = 0.080
- o Industrial 0.072 x 0.75 = 0.054
- o Coin-Operated 0.163 x 0.67 = 0.109

which correspond to mileages of

o Commercial	8,940
o Industrial	13,200
o Coin-Operated	6,600

Then, if better maintenance and housekeeping procedures were implemented in all of the plants, the mileage would increase to the levels indicated in the table of estimated plant mileages for housekeeping plus adsorber.

To determine the current average PCE consumption rate, it is necessary to estimate how many cleaners currently have carbon adsorbers. In a survey of its members, the International Fabricare Institute [15] found that about half of all dry cleaners have carbon adsorbers. We assume this to mean that half of the current commercial and coin-operated dry cleaners have adsorbers. However, because of the obvious economic benefits to industrial cleaners, it is assumed that 90 percent of industrial cleaners have adsorbers. Thus, the current average PCE consumption rates are taken to be as follows:

Commercial	0.5 x 0.119 + 0.5 x 0.080 = 0.099
Industrial	0.1 x 0.072 + 0.9 x 0.054 = 0.056
Coin-Operated	0.5 x 0.163 + 0.5 x 0.109 = 0.136

The next data elements to consider are the average cleaning volumes by type of plant. In their analysis, the authors of [3] used the following values, which were representative of survey results:

Commercial	100,000 pounds/year
Industrial	1,000,000 pounds/year
Coin-Operated	80,000 pounds/year

However, data from Ludwig [10] indicated that the average volume of commercial cleaners was 2,900 pounds per week, or about 150,000 pounds per year. We shall use the average of the two values, which implies the following average cleaning volumes:

Commercial	125,000 pounds/year
Industrial	1,000,000 pounds/year
Coin-Operated	80,000 pounds/year

Taking the estimated number of plants that use PCE from Section 2, we can estimate the total volume of cleaning by type of cleaner.

Type of Cleaner	Number	Cleaning Volume (pounds)	Cleaning Volume (kg)
Commercial	16,000	2000 x 10^6	900 x 10^6
Industrial	350	350 x 10^6	160 x 10^6
Coin-Op	11,000	880 x 10^6	400 x 10^6

Recall that multiplying the average consumption rate by the total cleaning volume will give total PCE consumption. Carrying out this multiplication gives the following accounting of PCE consumption:

	Consumption Rate		Cleaning Volume (kg)		PCE Consumption (kg)
Commercial	0.099	x	900×10^6	=	90×10^6
Industrial	0.056	x	160×10^6	=	9×10^6
Coin-Op	0.136	x	400×10^6	=	54×10^6
			Total		152×10^6

This total agrees well with the independent estimate of 160×10^6 kg of PCE [4]. For calculating reductions in PCE exposure to urban residents, reductions in total PCE consumption resulting from controls are compared to the assumed base case of 152×10^6 kg.

Data required to estimate the cost of control options include the cost of control equipment, estimated increases in maintenance costs, and the price of PCE. Since the equipment costs in [8] correspond to prices in 1975, we assume price increases to convert to 1978 dollars. For cleaning equipment, we use the producer price index for general purpose machinery [13], which increased by a factor of 1.21 between 1975 and 1978. From [8], the estimated costs of carbon adsorbers including installation (in 1978 dollars) were

o Commercial	\$5,000
o Industrial	\$9,100
o Coin-Operated	\$7,300

and the costs of cleaning machines were

o Commercial (40-pound capacity)	
--Transfer Unit	\$ 21,000
--Dry-to-dry unit	\$ 28,000
o Industrial (200-pound capacity)	
--Transfer Unit	\$114,000
o Coin-Operated (25-pound capacity)	
--4 dry-to-dry units	\$ 39,000

133

From Appendix A, the capital charge rate for dry cleaners is assumed to be 0.097. That is, the annual charge for a capital expenditure is 0.097 times that expenditure. Thus, the annual costs of adding a carbon adsorber are

Commercial	$485
Industrial	$880
Coin-Operated	$708

As in [8], we assume that the cost of annual maintenance of the carbon adsorbers would be 5 percent of their cash price. Thus, annual maintenance for the adsorbers is taken to be

Commercial	$250
Industrial	$455
Coin-Operated	$365

Using the same estimate of 5 percent of the equipment cost for maintenance of the dry cleaning machines and assuming that implementing improved maintenance and housekeeping would increase this cost by 50 percent, the additional annual cost of improved maintenance would be

Commercial	$ 525
Industrial	$2,850
Coin-Operated	$ 975

For commercial dry cleaners, this estimate is based on a transfer unit rather than on a dry-to-dry unit.

Finally, to complete the cost estimates for options 1 through 4, it is necessary to have a price for PCE. From [8], the price of PCE to dry cleaners in 1975 was $2.80 per gallon. Using the price index for chemicals and allied products that increased by a factor of 1.10 from 1975 to 1978, we have the estimated PCE price in 1978 of $3.10 per gallon. With 5.9 kg of PCE per gallon, the PCE price is $0.53 per kg.

To complete the cost and exposure estimates for option 5, we need the difference in cost between transfer and dry-to-dry units of equivalent capacity. From the above data, this difference is $7,000, which is annualized to 0.097 x 7000 = $680. This cost would apply to about 80 percent of existing commercial cleaners, since about 20 percent already have dry-to-dry units. Recall that in option 5, the replacement of transfer units by dry-to-dry units is assumed to be accomplished when the cleaning machine needs to be replaced anyway so that no additional expense besides the difference in machine costs needs to be considered. The resulting annual cost of the option can thus be viewed as the long-run increase in annual costs.

To complete the exposure analysis of option 5, it is necessary to estimate the reduction in worker exposure by switching to a dry-to-dry unit. From Ludwig [10], the average PCE concentration in the processing area was 31 ppm, but during a 15-minute period after the transfer operation, the average concentration was 64 ppm. Assuming 8 transfers per day in an 8-hour day, the concentration during the other 45 minutes per hour must have been 20 ppm in order for the daily average to be 31 ppm. That is

$$\frac{15 \times 64 + 45 \times 20}{60} = 31$$

By eliminating the transfer process, we may assume that the concentration in the machine area would average 20 ppm for the entire day. This is about a one-third reduction in PCE exposure to machine operators, which is assumed for the remainder of the analysis.

To complete the analysis of option 6 (moving coin-operated dry cleaning machines to a room separate from coin-operated laundry facilities), we assume the following. We assume that the rearrangement of equipment in a typical coin-operated laundry would require an additional 50 square feet at a monthly rental cost of $0.50 per square foot, or an annual cost of $300. We assume that remodeling would cost $1500, which would be capitalized and charged at the same annual rate as other dry cleaning investments; this comes to $145 per year. We assume that the effect on exposure is to reduce exposure to coin-operated laundry users by 90 percent, without changing exposure to any other group.

This completes the data and assumptions needed to apply the cost and exposure calculations described in the previous subsection.

RESULTS OF COST AND EXPOSURE CALCULATIONS

Appendix B contains the detailed calculation of costs and exposure reductions. The results are summarized in Table 4-2. The control costs are expressed in millions of dollars per year, and the exposure reduction estimates are multipliers applied to the exposures calculated in Section 3. Note that many of the control costs are actually negative. These cost reductions result from the large PCE credits that can be obtained with options 1, 2, and 3 and their combinations. Because of the cost savings, these options would be desirable even if exposures were not reduced. Section 7 analyzes the value of all options including those that actually result in a net cost.

Table 4-2

SUMMARY OF CONTROL COSTS AND EXPOSURE REDUCTION FACTORS BY CONTROL OPTION

	Control Option				
	1	2	3	4	5
Control Cost (millions of dollars)	-11.5	-2.2	-3.3	0.3	8.7
Exposure Reduction (multiplier)					
Workers					
Machine Operators					
Commercial	0.60	1.00	0.81	1.00	0.66
Industrial	0.67	1.00	0.96	1.00	1.00
Coin-Operated	1.00	0.55	1.00	0.67	1.00
Other Workers					
Commercial	0.60	1.00	0.81	1.00	1.00
Industrial	0.67	1.00	0.96	1.00	1.00
Coin-Operated	1.00	0.55	1.00	0.67	1.00
Service Users					
Commercial Dry Cleaners	0.56	1.00	0.89	1.00	1.00
Coin-Operated Dry Cleaners	1.00	0.59	1.00	0.74	1.00
Coin-Operated Laundry	1.00	0.55	1.00	0.67	1.00
Urban Residents (distance from dry cleaners, meters)					
25 - 200	0.72	0.84	0.89	0.93	1.00
200 - 500	0.72	0.84	0.89	0.93	1.00
500 - 1000	0.72	0.84	0.89	0.93	1.00

137

Table 4-2 (continued)

	Control Option				
	6	7	8	9	10
Control Cost (millions of dollars)	4.9	-13.5	-13.0	-10.1	-4.3
Exposure Reduction (multiplier)					
Workers					
Machine Operators					
Commercial	1.00	0.60	0.49	0.49	0.32
Industrial	1.00	0.67	0.64	0.64	0.64
Coin-Operated	1.00	0.55	0.55	0.44	0.55
Other Workers					
Commercial	1.00	0.60	0.49	0.49	0.49
Industrial	1.00	0.67	0.64	0.64	0.64
Coin-Operated	1.00	0.55	0.55	0.44	0.55
Service Users					
Commercial Dry Cleaners	1.00	0.56	0.49	0.49	0.49
Coin-Operated Dry Cleaners	1.00	0.59	0.59	0.50	0.59
Coin-Operated Laundry	0.10	0.55	0.55	0.44	0.55
Urban Residents (distance from dry cleaners, meters)					
25 - 200	1.00	0.57	0.52	0.48	0.52
200 - 500	1.00	0.57	0.52	0.48	0.52
500 - 1000	1.00	0.57	0.52	0.48	0.52

Table 4-2 (continued)

	Control Option				
	11	12	13	14	15
Control Cost (millions of dollars)	-8.1	-1.4	-5.2	0.6	3.5
Exposure Reduction (multiplier)					
Workers					
Machine Operators					
Commercial	0.49	0.49	0.49	0.32	0.32
Industrial	0.64	0.64	0.64	0.64	0.64
Coin-Operated	0.55	0.44	0.44	0.55	0.44
Other Workers					
Commercial	0.49	0.49	0.49	0.49	0.49
Industrial	0.64	0.64	0.64	0.64	0.64
Coin-Operated	0.55	0.44	0.44	0.55	0.44
Service Users					
Commercial Dry Cleaners	0.49	0.49	0.49	0.49	0.49
Coin-Operated Dry Cleaners	0.59	0.50	0.50	0.59	0.50
Coin-Operated Laundry	0.055	0.44	0.044	0.055	0.044
Urban Residents (distance from dry cleaners, meters)					
25 - 200	0.52	0.48	0.48	0.52	0.48
200 - 500	0.52	0.48	0.48	0.52	0.48
500 - 1000	0.52	0.48	0.48	0.52	0.48

Section 5

HEALTH EFFECTS OF PERCHLOROETHYLENE

This section of the report presents an overview of the extensive literature on the health effects of perchloroethylene. The first part of the section discusses the noncarcinogenic health impacts and is taken primarily from a recent NIOSH report [10]. The second part summarizes information from the CAG assessment [1] and the SAB review meeting [2] regarding the potential carcinogenicity of PCE.

TOXICOLOGICAL IMPACTS OF PERCHLOROETHYLENE

Perchloroethylene is a volatile liquid at room temperature with an odor threshold in the range of 5 to 50 parts per million in air. Its use as a dry cleaning solvent was motivated primarily by its nonflammability, as petroleum solvents pose a risk of explosion and fire.

Toxic effects from PCE are well established, with the principal target organ being the liver [10]. Liver enlargement and abnormal liver function tests, pathological changes in the kidneys, and depressive effects on the central nervous system have been observed in animal experiments [19-24]. Some animal evidence for skin irritation and adverse impacts on fetal development is also available [25,26]. Clinical evidence demonstrates that PCE is toxic to the liver in humans [27-30]. Additional PCE effects on humans are irritation of the eyes, upper respiratory tract, and sinus cavities; skin burns; headache; and central nervous system depression [19,27,29,31,32].

The most common exposure route for PCE is inhalation. If ingested, PCE enters the body through the intestines. Absorption through the skin is considered to be of lesser importance. PCE is retained in body fat and metabolized relatively slowly. The half-life for urinary excretion is estimated to be six days [33].

Occupational standards for PCE exposure reflect concern for the acute toxic effects. The allowed eight-hour time-averaged concentration is 100 ppm, with a ceiling concentration of 200 ppm, not to exceed a maximum peak of 300 ppm for 5 minutes in a 3-hour period [10]. NIOSH recommended in 1976 that occupational levels be reduced to a maximum of 50 ppm, averaged over a 10-hour workday or 40-hour work week, and a ceiling concentration of 100 ppm determined by 15-minute samples [34].

CARCINOGENIC EFFECTS OF PERCHLOROETHYLENE

Summary of Information

The major evidence for the potential carcinogenicity of PCE is a rodent bioassay carried out by the National Cancer Institute (NCI) using B6C3F1 mice and Osborne-Mendel rats [35]. The animals were given PCE in corn oil through a stomach tube five days a week for eighteen months. The B6C3F1 mice showed a statistically significant incidence of liver tumors (hepatocellular carcinomas), as shown in Table 5-1, which is reproduced from [1]. The bioassay on rats gave negative results, which NCI considered to be inconclusive because of high mortality. While chronic respiratory and kidney disorders were observed, there were no hepatocellular carcinomas observed in any of the exposed rats and no statistically significant tumor incidence at any anatomical site.

In addition to the NCI bioassays, a test was carried out on Sprague-Dawley rats by Dow Chemical [36]. This test involved inhalation of PCE vapor at 300 and 600 ppm. Although many tumors were found in both treated and control animals, there was no statistically significant increase in tumor incidence excepting an unusual tumor (adrenal pheochromocytoma) in the low dose female rats.

The results for short-term tests of PCE are inconclusive. In six bacterial systems and one mammalian cytogenic study, only one bacterial system indicated that PCE is mutagenic. A cell transformation study of Fischer rat embryo cells indicates that these highly sensitive cells can be transformed by PCE into tumor-producing cells.

Table 5-1

INCIDENCE OF HEPATOCELLULAR CARCINOMAS
IN B6C3F1 MICE FED TETRACHLOROETHYLENE

Dose (mg/kg/day)*	Hepatocellular Carcinomas
Male	
untreated	2/17 (12%)
vehicle control	2/20 (10%)
536	32/49 (65%)
1072	27/48 (56%)
Female	
untreated	2/20 (10%)
vehicle control	0/20 (0%)
386	19/48 (40%)
772	19/48 (40%)

---

*Time-weighted average doses.

Source: [1]

Limited epidemiological data have been obtained for dry cleaning and laundry workers. Preliminary results by Blair et al. [37] for 330 former members of dry cleaning union locals indicate an excess of lung, cervix, uterine, and skin cancer compared to the proportionate mortality for the U.S. population. A very recent study by Lin and Kessler [38] using a case-controlled survey method indicates increased incidence of pancreatic cancer among workers in garages and dry cleaning establishments. (This latter study was not included in the CAG review.) The small samples and methodological limitations of these epidemiological studies make them at most suggestive and not conclusive evidence that PCE induces cancer in humans.

The SAB Review

The CAG assessment of PCE was critically reviewed by the SAB Subcommittee on Airborne Carcinogens [2]. Many objections were raised regarding the evidence for the carcinogenicity of PCE, and the subcommittee declined to endorse the implication from the IRLG guidelines that the positive bioassay in B6C3F1 mice should be sufficient to imply that PCE be regarded as a carcinogen. The specific issues raised by the scientists at this meeting included the purity of the PCE, the absence of evidence for a genetic mechanism to induce the liver tumors observed in the B6C3F1 mice, and the appropriateness of the mouse as a species for extrapolating a carcinogenic risk to humans.

The first area of concern expressed by the scientists was whether PCE was in fact responsible by the observed mutagenic or carcinogenic effects. The PCE for the NCI bioassay was described as more than 99 percent pure, but with unknown impurities. Ames test data [39] showed that perchloroethylene containing a stabilizing chemical was mutagenic while unstabilized, purified PCE was not mutagenic in the activated bacteria system. Dr. Weinhouse, the chairman of the SAB subcommittee, expressed doubt based on the Ames data that the PCE used in the NCI bioassay "may have been stabilized with a substance that may be carcinogenic" ([2], p.141). The epidemiological data were similarly inconclusive, because dry cleaning workers are exposed to a number of potentially toxic chemicals in addition to PCE.

The second issue is that of genetic mechanism. Dr. Marvin Kuschner, the Dean of the School of Medicine at the State University of New York at Stoneybrook, described an alternative hypothesis: PCE is a liver toxin that produces extensive liver damage, and replication errors in regenerating liver cells in a strain of mouse prone to liver tumors result in a higher incidence of the tumors. Dr. Kuschner remarked that the available evidence indicates that PCE interacts with protein and not with the cell DNA. He noted that binding to protein may be a mechanism for toxicity to the cell, not alteration of the cell to cause a tumor. PCE may therefore cause a chemical hepatectomy, a removal of part of the liver. The implication of this hypothesis is that a threshold or strong nonlinearity in the dose response relationship should exist. Exposure to PCE at levels below that at which cell destruction takes place should not result in tumors.

The third issue is the basis for extrapolating from bioassay data to humans in assessing risk. Dr. Raymond Harbison of Vanderbilt Medical Center and Dr. Jessie Norris of Dow Chemical made presentations to the SAB meeting [2], stressing the metabolic differences between mice, rats, and humans. Perchloroethylene is transformed to an epoxide intermediate through a metabolic activation process. This reaction appears to go much faster in the mouse than in the rat or in man, based on studies that use carbon-14 labelled PCE to track its metabolic pathways [2,40,41]. Gross changes in the liver of mice occur well below maximum tolerated dosage levels, while rats appear to be much less sensitive to liver damage from PCE even at high doses. A dose-related increase of liver cell DNA synthesis was observed in mice, but not in rats. The ability of the mouse to metabolize PCE saturates at high doses, providing a possible explanation for the apparent saturation in tumor response that was observed in the B6C3F1 mouse data.

The limited human clinical data suggests that man metabolizes less PCE than either mice or rats. Dr. Norris of Dow asserted that the rat and not the mouse was the appropriate species on which to base a risk assessment. She presented a risk assessment based on the Dow rat study [36], taking 300 parts per million or 253 milligrams per kilogram of body weight per day as a level for no observed adverse effect in the rat [40]. Although Dr. Norris derived a margin of safety of 118,000 for humans, this assessment assumes an atmospheric concentration of one part per billion PCE for human exposure. Occupational exposures can be four to five orders of magnitude higher, reducing the margin of safety in this calculation to a factor of ten or less for exposed wokers.

A related problem in assessing the human risk based on rodent bioassays is the calculation of an equivalent human dose corresponding to rodent exposures. While the IRLG guidelines cite a National Academy of Sciences study [42] in support of using total dose per body weight as a basis for extrapolating from animals to humans, the CAG methodology for air pollutants uses relative surface area [43]. CAG's procedure appears to be based on a suggestion of Mantel and Schneiderman, which is based on the observation that the effective dose of drugs scales better with surface area than body weight weight [44]. As a caveat CAG notes

> ...the concept of equivalent doses for humans compared to animals on a mg/surface area basis is virtually without experimental verification regarding carcinogenic response. ([43], p.15)

CAG's use of surface area was challenged at the SAB meeting by Dr. A. M. Schumann of Dow in the context of trichloroethylene:

> Rodents metabolize trichloroethylene (TCE) to a greater extent than do humans on a weight basis and are thus exposed to much more reactive TCE intermediate than humans. Therefore, the corrected equation for trichloroethylene species comparison is the reciprocal of that used in the CAG assessment. ([2], p. 163)

The surface area extrapolation procedure was not discussed specifically for PCE in the SAB meeting, but the issues for PCE and TCE are very similar. Dr. Norris used an extrapolation on body weight in her calculation [40].

Section 6

MODEL FOR DOSE RESPONSE RELATIONSHIP FOR PCE

This section presents a model for the dose response relationship for PCE. Our objective is to develop a representation of the uncertainty in human cancer incidence given PCE dose that might be used as a basis for determining unreasonable risk under the language of the Toxic Substance Control Act. The calculation is intended to be illustrative, based on the data and discussion from the CAG Assessment [1] and the SAB meeting transcript [2].

It was pointed out by Dr. Altshuler in [2] that an estimate of cancer risk to the population can be obtained by multiplying an exposure estimate by CAG's unit risk estimate. Dr. Albert and Walter Barber of EPA responded that EPA has not yet determined how to use these estimates in the regulatory process. A recent National Academy of Sciences study [45] was strongly critical of the CAG unit risk approach because a single number could provide an illusion of certainty, whereas in reality the health effects of a suspected carcinogen might be uncertain over many orders of magnitude.

In developing our approach, we shall endeavor to account for major sources of uncertainty in estimating the human health impact of a given level of PCE exposure. After a review of the discussion in [2], we concluded that the most important sources of uncertainty are as follows:

1. Should one extrapolate from rodents to humans based on surface area as suggested by CAG, by body weight as suggested by the National Academy of Sciences, or on some other basis?
2. Should the extrapolation be from the most sensitive species, the B6C3F1 mouse, or from a species metabolically more similar to humans, such as the rat used for Dow's inhalation studies?
3. Should a linear nonthreshold dose response relationship be used, or should a nonlinear or nonzero threshold relationship be used

that is more representative of the hypothesis that PCE acts indirectly in causing mouse liver tumors through a cell toxicity mechanism?

For our illustrative calculations, we shall examine two alternative cases for each of these questions. To develop a probability distribution on health impacts, we shall assess probabilities for these cases. Ideally, these probabilities should reflect the judgment of scientific specialists on the issues, but for our purposes, the authors will use three sets of illustrative values:

1. A probability assessment of 20 percent to the assumptions used by CAG and 80 percent to the alternative.
2. A probability assessment of 33 percent to the CAG assumptions and 67 percent to the alternative.
3. A probability assessment of 50 percent to each alternative case.

We shall consider that the probability assignments for each of the three uncertain factors are independent: Resolution of uncertainty on one factor would not affect the probabilities assigned to the alternatives for the other two factors. Two representative outcomes for each of three factors give a total of eight cases that we shall consider. Additional factors and additional representative cases for each factor could be included without changing the methodology, but for simplicity, we have chosen to limit the analysis to eight alternative cases for the dose response relationship.

We now describe the specific assumptions used in determining the quantitative descriptions for the representative outcomes for each of the three factors treated as uncertain.

SCALING METHOD

The two cases correspond to the surface area extrapolation method proposed by CAG [1] and the method of extrapolation by body weight. In the CAG surface area method, the equivalent dosage for humans measured in milligrams per kilogram of body weight is reduced from the dosage measured in milligrams per kilogram of body weight that was actually administered to rodents by a factor equal to the cube root of human body weight divided by rodent body weight. Thus, for example, the reduction factor in going from a 30-gram mouse* to a 70-kilogram human is

$$\left(\frac{70}{0.03}\right)^{1/3} = 13.26$$

In the body weight extrapolation method, no such reduction factor is used. The dosage to rodents in milligrams per kilogram of body weight is considered equivalent to the same dosage in milligrams per kilogram of body weight ingested in a human. The ratio of absolute dosage is the same as the ratio of body weights, for example, (70/0.03) = 2333 for human to mouse.

SPECIES TYPE FOR EXTRAPOLATION

Laboratory animal strains are highly inbred, genetically similar and, therefore, homogeneous populations for which reproducible results may be obtained. Human populations are genetically heterogeneous and may exhibit a much broader range of sensitivities to biological insults than the animal strains used in bioassays. While some scientists and regulators believe that use of the most sensitive species and genetic strain is appropriate to avoid underestimating the potential risk to sensitive human subpopulations, other scientists stress the biological and metabolic differences between humans and the small rodents typically used as laboratory animals. For some chemicals there may be substantial scientific grounds for believing that an effect observed, for example, in mice but not in rats, is highly unlikely to occur in humans because the way the rat metabolizes the chemical is similar to humans and the metabolic process for the mouse is significantly different. For our analysis we consider two cases, one based on mouse data and the other on rat data. Both the mouse and rat are of a genetic strain that is particularly sensitive to liver tumors.

---

*In the CAG documentation [1,43] the mouse is assumed to weigh 30 grams and the rat 350 grams.

Our two representative cases are based on the results of the NCI test using B6C3F1 mice and the Dow tests with Sprague-Dawley rats.* We prefer the use of the maximum likelihood estimate for reasons articulated by Altshuler in [2] for the frequency of tumors in the exposed animals. A correction term should be employed if there is a substantial incidence of the tumors in the control group. For our analysis, we use the observed incidence in male mice of 32/49 or 65 percent at the dose level of 536 milligrams/kilogram/day for five days per week over 78 weeks [1].** The test was terminated after 90 weeks resulting in a lifetime exposure of 332 mg/kg/day.

For the rat results, we have used a conservative figure of a five percent incidence. No statistically significant elevated tumor incidence was observed in the Dow rat study. However, the small sample size of the experiment makes it difficult to conclude that a small incidence of tumors is not present. An experimental result of no tumors in 100 animals has an upper 99 percent confidence limit for the incidence rate of 3.6 percent. Since both the Dow study and the NCI rat study are considered by CAG [1,2] to have deficiencies as the basis for a negative finding (no tumor incidence), we have used as an estimate a low (five percent) rate of incidence at the lower (300 ppm or 253 mg/kg/day) administered dose in the Dow study. This judgment by the authors is illustrative and should be subjected to review by qualified experts. The estimate of five percent in the rat leads to much lower numbers for cancer incidence in humans than do the estimates from the B6C3F1 mouse data.

---

*The NCI bioassay in Osborne-Mendel rats suffered from high mortality. The CAG assessment [1] notes that no hepatocellular carcinomas were observed in any exposed rats, and that no statistically significant tumor incidence was observed at any anatomical site, but provides no further data. The CAG assessment [1] does provide the data for the Dow study, but concludes that the study has limitations that make it "inadequate to assess the carcinogenicity or noncarcinogenicity" of PCE because (1) the exposure was for 12 months rather than a full lifetime of 24 months, (2) the exposure levels were too low, and (3) control animals were not properly separated from treated animals. The Dow study appeared to us to provide a better basis for a representative case than the NCI study.

**An upper 95 percent confidence limit value would correspond to an incidence rate of 73.5 percent tumors in the exposed mice. The difference in the analysis from using this figure would be to increase the cancer incidence by about 10 percent in the four cases extrapolated from the mouse data.

EXTRAPOLATION MODEL

We employ a model for extrapolating from the high doses administered in animal experiments to the lower doses corresponding to human exposure. Two alternative models are used. The first is a linear, nonthreshold dose response model fitted to the single bioassay data point available, either for the B6C3F1 mouse or the Sprague-Dawley rat as previously described. For the alternative model, we assume a quadratic model of the form incidence proportional to dose squared. Such a model is representative of nonlinear relationships without assuming a threshold for tumor incidence. It is consistent with observed nonlinearities observed for some carcinogens [46] but does not assume that tumor incidence rate changes rapidly with dose.

The form of the model is the multistage model described in the IRLG guidelines [3].

$$P(d) = 1 - \exp\left(- \lambda_0 - \sum_{i=1}^{k} \lambda_i d^i\right), \ \lambda_i \geq 0 \qquad (6.1)$$

P(d) is the probability of cancer occurrence given a dose level d. We have assumed no background incidence ($\lambda_0 = 0$) and we assume either a linear ($k = 1$) or pure quadratic form: ($k = 2$, $\lambda_1 = 0$). Therefore, for each case we compute the parameter λ (λ_1 for the linear case or λ_2 for the quadratic case) from the animal test data relating the observed lifetime cancer incidence to dosage level in milligrams/kilogram/day. We then use the above formula to predict human lifetime cancer incidence corresponding to various PCE human exposure levels, translating appropriately from micrograms per cubic meter to milligrams/kilogram/day for a 70-kilogram person. The value of the parameter λ and the calculations of human cancer incidence for each case are given in Appendix C.

The attribution of the linear model to CAG deserves additional comment. The CAG assessment procedures use the multistage model, equation (6.1), and a computer program to estimate the coefficients λ_i for the upper confidence limit. As noted in [43] this is equivalent to using a linear relation for low dose extrapolation. A discussion of this equivalence is found in Guess and Crump [47].

Section 7

ANALYSIS OF CONTROL OPTIONS

This section brings together the cost and exposure calculations of Sections 3 and 4 with the dose response calculations of Sections 5 and 6 to choose a best alternative control option. To choose the best option, probabilities must be assigned to uncertain outcomes, and values must be assigned to trade off control costs with expected cancer cases. The best choice depends on these probabilities and value assignments. Following a base case selection of an option, sensitivity analysis is performed to explore the effect of changes in probabilities and values on the choice of the best option.

STRUCTURE OF THE CONTROL DECISION

The decision of selecting a PCE control option for the dry cleaning industry is represented in Figure 7-1. The alternative decisions, as shown at the left of the figure, are to do nothing or to select one of the options 1 through 15. From our analysis of Section 4, the selection of one of these alternatives determines the control cost and the average level of exposure to the twelve population groups used in that analysis. Of course, uncertainties exist in both the cost and the exposure estimates. However, it is reasonable to expect that these uncertainties are far less significant than the uncertainty in the number of cancer cases that may result from those exposures. The uncertainty in possible cancer cases is modeled explicitly through the selection of alternative dose response models for extrapolating test results from animals to humans and from high to low doses. From Section 6, the difference in predicted cancer incidence among the alternative models can be five orders of magnitude. These uncertainties clearly dominate uncertainties in exposure levels, which are probably less than one order of magnitude.

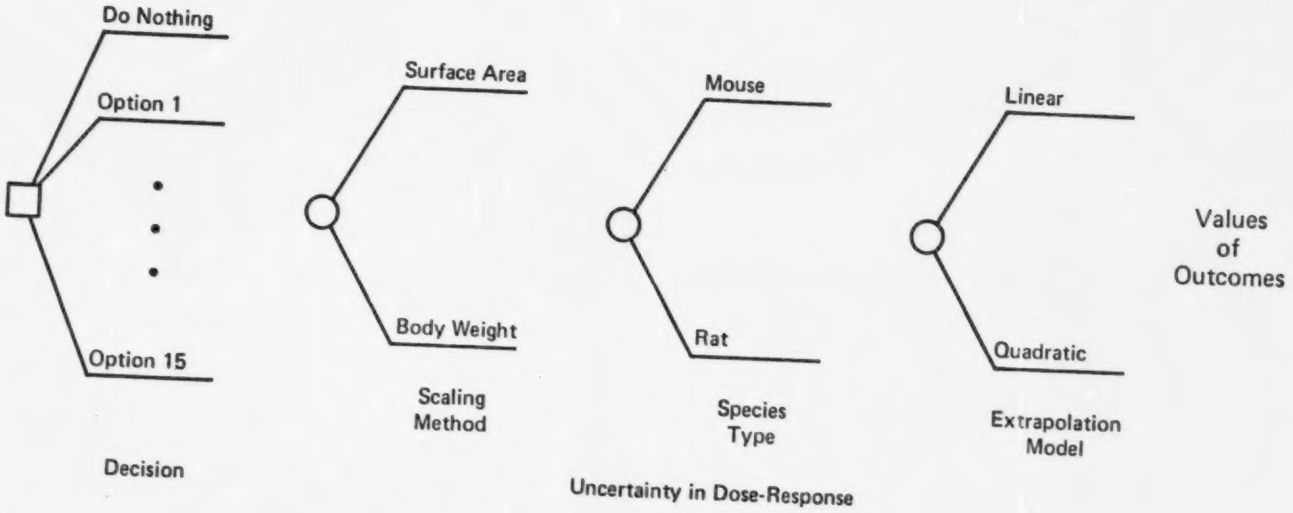

Do Nothing
Option 1
Option 15
Decision
Surface Area
Body Weight
Scaling Method
Mouse
Rat
Species Type
Uncertainty in Dose-Response
Linear
Quadratic
Extrapolation Model
Values of Outcomes

Figure 7-1. Decision Tree for PCE Control Analysis

The uncertainty in dose response is represented in the center of the decision tree of Figure 7-1. The dose response is assumed to have three independent components, each with two alternatives. The components are scaling method, species type, and extrapolation model. The scaling method determines how an equivalent dose is determined for different sized animals. The representative alternatives we have chosen are scaling methods based on dose per surface area or dose per body weight. The choice of species type involves using the observed response from either the mouse or the rat tests as the basis for extrapolation to humans. The extrapolation model is the method of extrapolating from high to low doses and can be taken to be either linear or quadratic, as described in Section 6.

Since the correct choice of each dose response component is not known, probabilities are assigned to each possibility. In Figure 7-1, p_1 represents the probability that the true scaling method is surface area. Thus, $1-p_1$ is the probability that the true scaling method is body weight. Similarly, p_2 is the probability that the true representative species is the mouse, and p_3 is the probability that the correct extrapolation model is linear. The probabilities $1-p_2$ and $1-p_3$ are assigned to the other possibilities of species and extrapolation model, respectively.

Each one of the eight possible combinations of dose response components gives a method for estimating the lifetime cancer incidence in humans, given an average daily dose of PCE. Taking the average life expectancy of 70 years, the annual cancer incidence rate for a group of people with the same average daily exposure would be

$$\text{Annual Cancer Cases} = \frac{\text{Number of People Exposed x Lifetime Incidence}}{70} \qquad (7.1)$$

Adding the number of cases for each population group would then give the total annual cancer cases resulting from PCE exposure.

The next step is to find the expected annual number of cancer cases using the probabilities of each dose response combination. Assuming probabilistic independence of the components of dose response, the probability of any combination is simply the product of the probabilities of the components. Each dose response combination and its probability are listed in Table 7-1.

Table 7-1

ENUMERATION OF DOSE RESPONSE CASES

Dose Response Combinations	Definition of Case Scaling Method	Species Type	Extrapolation Model	Probability
1	surface area	mouse	linear	$p_1 \times p_2 \times p_3$
2	surface area	mouse	quadratic	$p_1 \times p_2 \times (1-p_3)$
3	surface area	rat	linear	$p_1 \times (1-p_2) \times p_3$
4	surface area	rat	quadratic	$p_1 \times (1-p_2) \times (1-p_3)$
5	body weight	mouse	linear	$(1-p_1) \times p_2 \times p_3$
6	body weight	mouse	quadratic	$(1-p_1) \times p_2 \times (1-p_3)$
7	body weight	rat	linear	$(1-p_1) \times (1-p_2) \times p_3$
8	body weight	rat	quadratic	$(1-p_1) \times (1-p_2) \times (1-p_3)$

Using the notations prob_i to represent the probability of dose response combination i (i = 1 to 8) and cases_i to represent the annual number of cases predicted by dose response combination i, then the expected annual number of cancer cases is given by

$$\text{Expected Annual Cancer Cases} = \sum_{i=1}^{8} \text{prob}_i \times \text{cases}_i \qquad (7.2)$$

The final part of the decision tree is the value component. Using the criterion of expected cost, the total annual cost of a control option and its impact on cancer incidence is given by

$$\begin{aligned} \text{Total Cost} = {} & \text{Control Cost} \\ & + \text{Expected Annual Cancer Cases} \\ & \times \text{Cost per Case} \end{aligned} \qquad (7.3)$$

where the expected number of cancer cases is given by (7.2), the control cost is the cost calculated in Section 4, and the cost per case is a value judgment made by the decision maker. Once the probabilities p_1, p_2, and p_3 are specified and the value judgment of cost per cancer case is made, each control option can be evaluated. The best control option is then simply the one with the least expected total annual cost.

SELECTION OF BEST CONTROL OPTION

Because of the large number of calculations required, the expected number of cancer cases for each control option and dose response combination was calculated with a computer program. The results are in Table 7-2, while the details of each computation are in Appendix C.* Note the wide differences in expected number of cancer cases as a function of dose response model. In the base case, no controls, the expected annual number of cases is 348, if we assume the dose response model consisting of surface area scaling, mouse species, and linear extrapolation. On the other hand, the expected number of cases is only 0.01 if we assume the dose response model of body weight scaling, rat species, and quadratic extrapolation. Intermediate values correspond to other combinations.

Examining the control options, we find that all of the options reduce the expected number of cancer cases as compared with the base case. Option 15, the combination of all control options, results in the least number of cancer cases for all dose response combinations. In examining the cost of controls, note that options 1, implementing better maintenance in commercial and industrial cleaners; 2, implementing better maintenance in coin-operated dry cleaners; and 3, installing carbon adsorbers in commercial dry cleaners, actually save money as well as reduce expected cancer cases. Option 7, which is a combination of options 1 and 2, is the least cost (greatest savings) of any of the options.

Since option 7 saves money and lowers expected cancer cases, it would always be preferred to the base case no matter what cost per cancer case is

---

*By expressing cancer cases and costs on an annual basis, we have avoided the controversial problem of discounting health effects that may occur in the future. A more detailed analysis could address this issue.

Table 7-2

CONTROL COSTS AND EXPECTED CANCER CASES

Control Option	Combination of Options	Expected Number of Cancer Cases Per Year by Dose Response Combination 1	2	3	4	5	6	7	8	Cost of Control Option ($ million)
Base Case	-	347.49	22.91	10.15	0.38	27.05	0.13	1.70	0.01	0.00
1	-	275.22	8.92	7.87	0.15	21.06	0.05	1.32	0.00	-11.30
2	-	276.67	22.47	8.08	0.38	21.62	0.13	1.36	0.01	-2.20
3	-	317.92	15.80	9.25	0.26	24.52	0.09	1.55	0.01	-3.30
4	-	296.61	22.56	8.71	0.38	23.12	0.13	1.46	0.01	0.30
5	-	330.74	14.41	9.57	0.24	25.49	0.08	1.59	0.01	8.70
6	-	239.21	22.88	7.10	0.38	18.89	0.13	1.19	0.01	4.90
7	1,2	204.41	8.48	5.87	0.14	15.71	0.05	0.99	0.00	-13.50
8	1,2,3	186.31	5.91	5.33	0.10	14.28	0.03	0.90	0.00	-13.00
9	1,2,3,4	169.25	5.85	4.87	0.10	13.01	0.03	0.81	0.00	-10.10
10	1,2,3,5	176.92	3.79	5.03	0.06	13.50	0.02	0.85	0.00	-4.30
11	1,2,3,6	126.73	5.91	3.66	0.10	9.81	0.03	0.62	0.00	-8.10
12	1,2,3,4,5	169.25	5.85	4.87	0.10	13.01	0.03	0.81	0.00	-1.40
13	1,2,3,4,6	121.59	5.85	3.51	0.10	9.42	0.03	0.59	0.00	-5.20
14	1,2,3,5,6	117.34	3.76	3.36	0.06	9.02	0.02	0.57	0.00	0.60
15	1,2,3,4,5,6	112.19	3.70	3.22	0.06	8.64	0.02	0.54	0.00	3.50

assumed. The question is whether or not there is another option that gives enough reduction in cancer to be worth the additional cost as compared with this option.

To illustrate the process of selecting the best option, we might assess the probabilities in the dose response model as follows:

p_1 = 0.2 (20% chance that surface area is the appropriate basis for extrapolation and 80% chance that body weight is the approriate basis for extrapolation)

p_2 = 0.2 (20% chance that the mouse is appropriate as a model for humans and 80% chance that the less sensitive rat is appropriate)

p_3 = 0.2 (20% chance that the dose response relation is linear and 80% chance that it is nonlinear [quadratic])

The probabilities of each dose response combination are then computed to be

Dose Response Combination	Probability
1	0.008
2	0.032
3	0.032
4	0.128
5	0.032
6	0.128
7	0.128
8	0.512

We have also assumed a value of one million dollars per cancer case. Then using (7.3), we compute the expected annual cost and display it in Table 7-3. We find that option 7, with a net savings of $10.75 million, is found to be the least cost option, including both control costs and cancer costs valued at one million dollars per case. Note that option 8, which includes option 7 plus the installation of carbon adsorption units in commercial dry cleaners, is very close to option 7 in total cost. Increasing the value assigned per case of cancer by about 50 percent would cause the least-cost option to switch to option 8. The sensitivity of the optimal option to these values is explored in the next subsection.

Table 7-3

SELECTION OF OPTIMAL DECISION

Control Option	Expected Number of Cancer Cases per Year	Assumed Cost per Case ($ million)	Annual Control Cost ($ million)	Expected Annual Cost ($ million)
Base Case	4.99	1.0	0.0	4.99
1	3.61	1.0	-11.3	-7.69
2	4.13	1.0	-2.2	1.93
3	4.38	1.0	-3.3	1.08
4	4.37	1.0	0.0	4.67
5	4.48	1.0	8.7	13.18
6	3.70	1.0	4.9	8.60
7	2.75	1.0	-13.5	-10.75*
8	2.44	1.0	-13.0	-10.56
9	2.23	1.0	-10.1	-7.87
10	2.25	1.0	-4.3	-2.05
11	1.73	1.0	-8.1	-6.37
12	2.23	1.0	-1.4	0.83
13	1.67	1.0	-5.2	-3.53
14	1.54	1.0	0.6	2.14
15	1.47	1.0	3.5	4.97

*Least cost alternative in this example.

SENSITIVITY ANALYSIS

The optimal control option depends on the assumed cancer cost and the probabilities assigned to the dose response model. With the probability assignments as made in the previous subsection, the optimal decision depends on cancer cost as shown in Figure 7-2. For any value less than $1.61 million, option 7 is the least cost. For values between $1.61 and $6.90 million, the least cost option is option 8, and for values over $6.90 million up to at least $20 million, option 11 is optimal. Recall that option 11 consists of option 8 in addition to moving all coin-operated dry

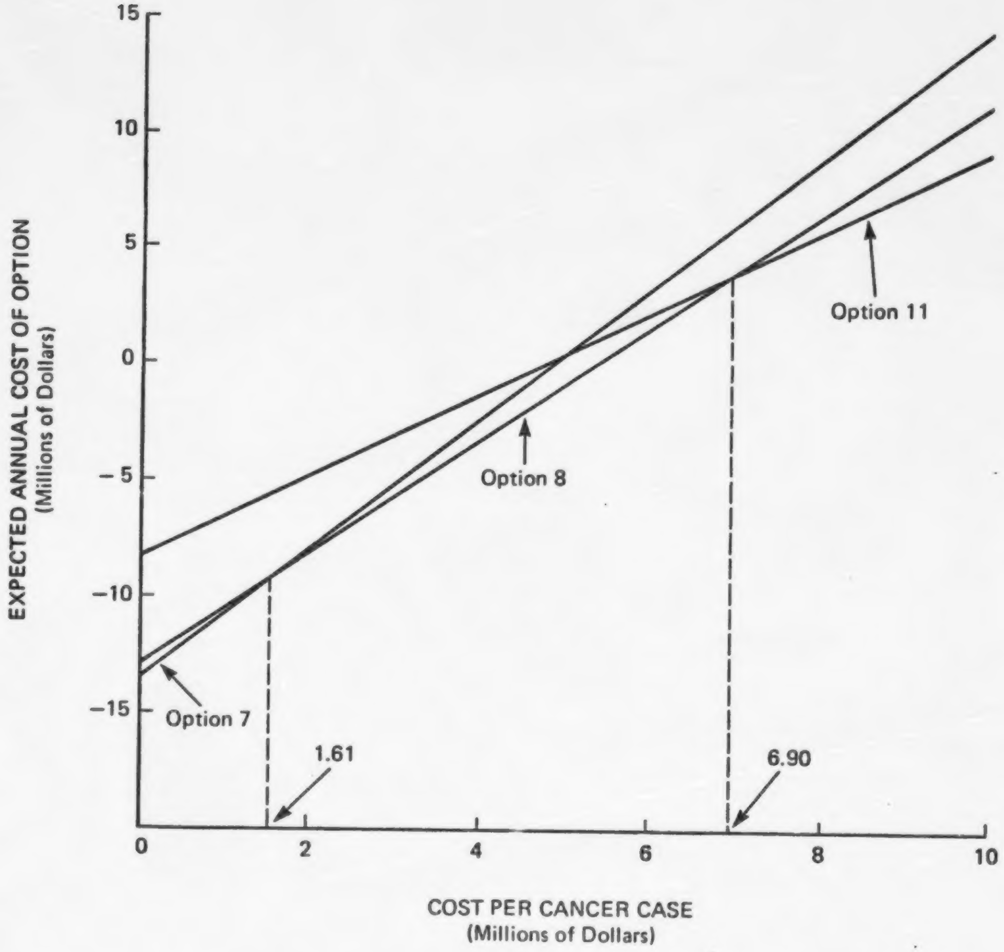


Figure 7-2. Sensitivity Analysis on Cost Per Cancer Case ($p_1 = p_2 = p_3 = 0.2$)

rooms separate from coin-operated laundries. Option 11 would cost about \$4.9 million more annually than would option 8. However, the value of reducing exposure to coin-operated laundry users is worthwhile with a high cost per expected cancer case.

The sensitivity of the optimal decision to changes in probability assessments is shown in Table 7-4. Here, the cancer cost is again assumed to be one million dollars, though the probabilities are varied. For a probability assignment of $p_1 = p_2 = p_3 = 0.33$, the optimal option switches from option 7 to option 8. For the probability assignment of $p_1 = p_2 = p_3 = 0.5$, the optimal option becomes option 11. Clearly, if higher probabilities are placed on dose response models that give higher levels of cancer incidence, more controls become attractive.

Table 7-4

SENSITIVITY ANALYSIS OF PROBABILITY ASSIGNMENTS

Control Option	Expected Annual Cost of Option (millions of dollars) $(p_1=p_2=p_3=0.2)$	$(p_1=p_2=p_3=0.33)$	$(p_1=p_2=p_3=0.5)$
Base Case	4.99	17.20	51.23
1	-7.69	1.58	28.02
2	1.93	11.83	39.14
3	1.08	12.03	42.88
4	4.67	15.22	44.42
5	13.18	24.48	56.47
6	8.60	17.32	41.12
7	-10.75*	-3.79	15.96
8	-10.56	-4.29*	13.61
9	-7.87	-2.15	14.14
10	-2.05	3.82	20.72
11	-6.37	-2.02	10.26*
12	0.83	6.55	22.84
13	-3.53	0.65	12.44
14	2.14	6.09	17.37
15	4.97	8.76	19.54

*Least cost alternatives for each set of probability assignments.

Section 8

VALUE OF FURTHER INFORMATION

In addition to having the choice of control option, the dry cleaning industry has the option of gathering more information. Under TSCA, EPA can require that industry obtain better information through such means as animal tests. Decision analysis can provide guidance as to the best time to obtain more information and can indicate which type of information would be most valuable. The value of information comes from its effect on decisions. In the analysis of PCE in dry cleaning, if we knew which dose response model were correct, in the sense of giving the best estimate of the true cancer risk, we might find a superior option to the one previously selected. The difference between the cost of this superior option and the expected cost of the best option without the information is the measure of the value of that information. However, before we find out which dose response model is correct, we do not know which decision would be chosen on the basis of this new information. To account for this difficulty, we can calculate the expected value of obtaining perfect information using the previously assessed probabilities of each dose response model.

The expected value of perfect information (EVPI) found in this way will be an upper limit to the value of further information gathering. Real experiments, such as using larger groups of animals at lower PCE doses, do not give perfect information. Given a quantification of the possible results of real tests, one can calculate the expected value of information provided by any test [48,49]. Those calculations, which are only slightly more complicated than the ones below, are left for later analysis.

The expected value of perfect information on the entire dose response model is calculated using the decision tree in Figure 8-1. Here, the uncertainties are shown to be resolved before the decision is made. The

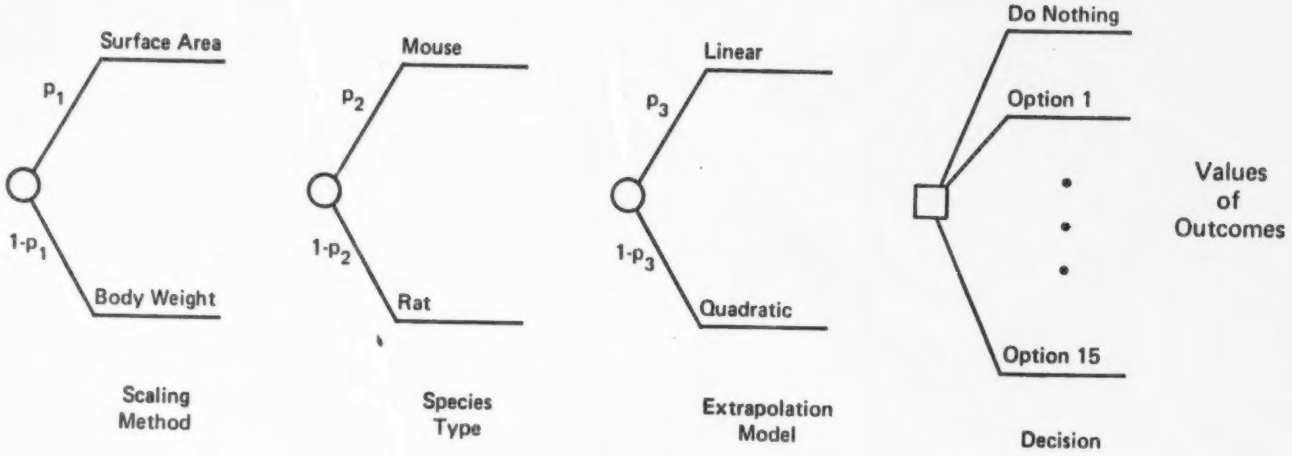

Surface Area
p_1
$1-p_1$
Body Weight
Scaling Method
Mouse
p_2
$1-p_2$
Rat
Species Type
Linear
p_3
$1-p_3$
Quadratic
Extrapolation Model
Do Nothing
Option 1
Option 15
Decision
Values of Outcomes

Figure 8-1. Decision Tree for Calculating Value of Perfect Information on All Dose Response Uncertainties

expected value for this decision problem is calculated in the usual way with the probabilities on each of the eight possible branches. Mathematically, the expected value of perfect information is simply

$$\text{EVPI} = EC_{wo} - EC_w \qquad (8.1)$$

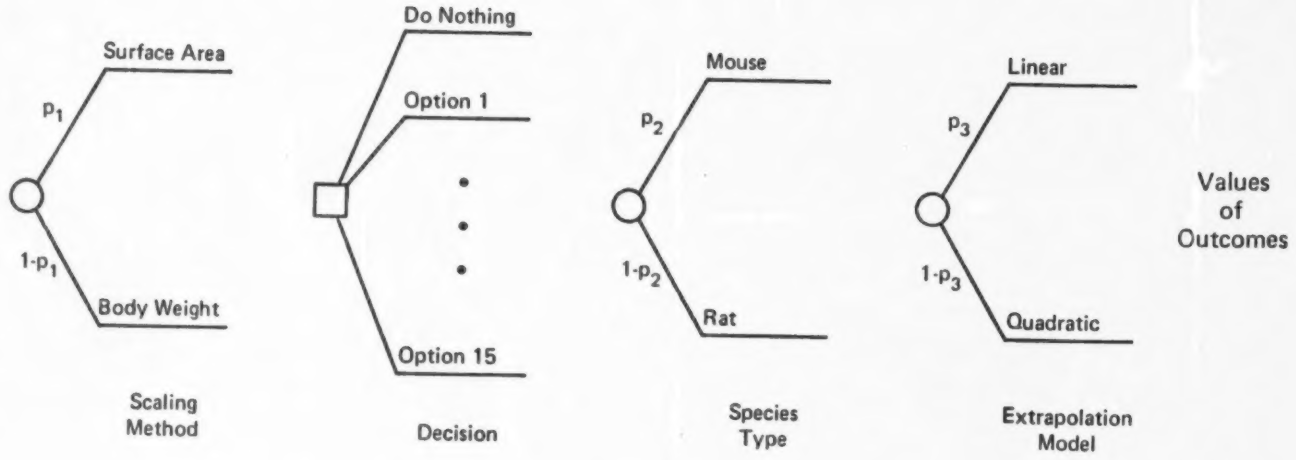
where EC_{wo} is the expected cost of the optimal control option without any additional information as calculated in (7.3) and EC_w is the expected cost of the eventual optimal control option with perfect information. EC_w is computed from

$$EC_w = \sum_i \text{prob}_i \times \text{cost}_i \qquad (8.2)$$

where prob_i is the probability that dose response case i is true and cost_i is the cost of the optimal control option given the knowledge that case i is true.

The data required to calculate the EVPI are in Table 8-1. The table shows the probability of the dose response model, the optimal decision given that model, and the expected annual cost of that optimal choice. Using the three sets of probabilities from the sensitivity analysis of Section 7-3 and a cost per cancer case of one million dollars, we calculate the corresponding expected values of perfect information, as shown in Table 8-2. For the base case probability assignments, the EVPI is $0.7 million per year. With the other probability assignments, it varies from $2.4 million to about $4 million per year. From these calculations, one may conclude that under reasonable probability assignments and cost per cancer case, it would be worthwhile to spend up to $4 million per year on tests to resolve all the dose response uncertainties.

In addition to considering all the dose response uncertainties together, we can examine the expected value of perfect information on each one separately. These values of EVPI are calculated using the decision trees of Figures 8-2 through 8-4. In each of the figures, a single component of the dose response model is resolved before the decision is made, and the other two are resolved after the decision. The decisions are thus made with the knowledge of the first component but not of the others. The expected value of perfect information is then calculated in the same way as in Tables 8-1 and 8-2. The results of these calculations are in Table 8-3.



Surface Area
p_1
$1-p_1$
Body Weight
Scaling Method
Do Nothing
Option 1
Option 15
Decision
Mouse
p_2
$1-p_2$
Rat
Species Type
Linear
p_3
$1-p_3$
Quadratic
Extrapolation Model
Values of Outcomes

Figure 8-2. Decision Tree for Expected Value of Perfect Information on Scaling Method

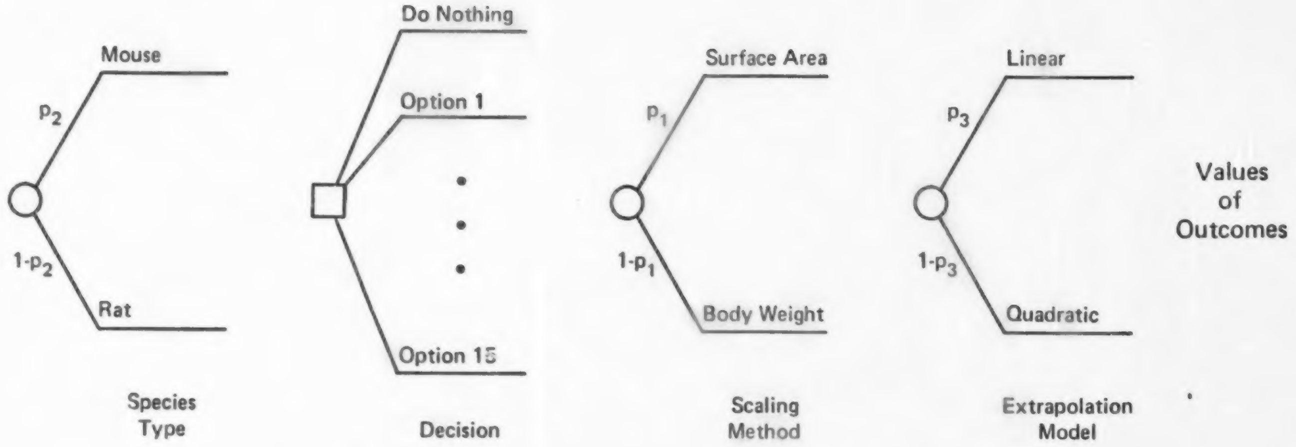

Mouse
p_2
$1-p_2$
Rat
Species Type
Do Nothing
Option 1
Option 15
Decision
Surface Area
p_1
$1-p_1$
Body Weight
Scaling Method
Linear
p_3
$1-p_3$
Quadratic
Extrapolation Model
Values of Outcomes

Figure 8-3. Decision Tree for Expected Value of Perfect Information on Species Type

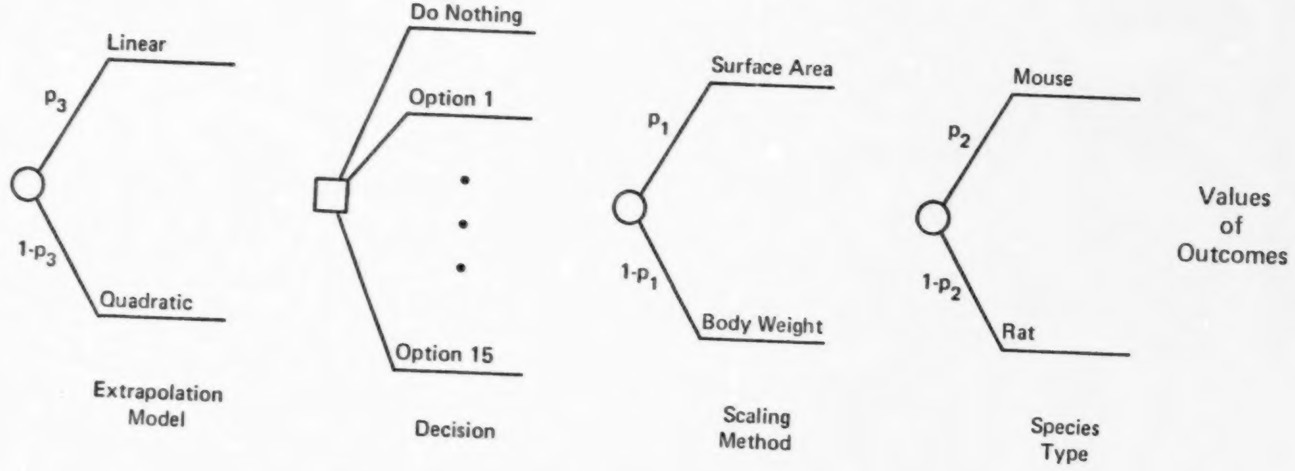

Linear
p_3
$1\text{-}p_3$
Quadratic
Extrapolation Model
Do Nothing
Option 1
Option 15
Decision
Surface Area
p_1
$1\text{-}p_1$
Body Weight
Scaling Method
Mouse
p_2
$1\text{-}p_2$
Rat
Species Type
Values of Outcomes

Figure 8-4. Decision Tree for Expected Value of Perfect Information on Extrapolation Model

These values vary from $0.15 million per year for the scaling method component under the base case probability assignments to $2.46 million per year for the extrapolation model component under the probability assignment $p_1 = p_2 = p_3 = 0.5$.

Table 8-1

DATA FOR CALCULATING EXPECTED VALUE OF PERFECT INFORMATION

Dose Response Combination	Probability	Optimal Options	Expected Annual Cost of Option ($ million/year)
1	$p_1 x p_2 x p_3$	15	115.69
2	$p_1 x p_2 x (1-p_3)$	8	-7.09
3	$p_1 x (1-p_2) x p_3$	8	-7.67
4	$p_1 x (1-p_2) x (1-p_3)$	7	-13.36
5	$(1-p_1) x p_2 x p_3$	8	1.28
6	$(1-p_1) x p_2 x (1-p_3)$	7	-13.45
7	$(1-p_1) x (1-p_2) x p_3$	7	-12.51
8	$(1-p_1) x (1-p_2) x (1-p_3)$	7	-13.50

Table 8-2

EXPECTED VALUE OF PERFECT INFORMATION ON ALL DOSE RESPONSE UNCERTAINTIES

Probability Assignment	Expected Cost Without Perfect Information ($ million/yr)	Expected Cost With Perfect Information ($ million/yr)	Expected Value of Perfect Information ($ million/yr)
$p_1=p_2=p_3=0.2$	-10.75	-11.45	0.70
$p_1=p_2=p_3=0.33$	-4.29	-6.71	2.42
$p_1=p_2=p_3=0.5$	10.26	6.17	4.09

Table 8-3

EXPECTED VALUE OF PERFECT INFORMATION ON EACH COMPONENT OF DOSE RESPONSE UNCERTAINTY

Probability Assignment	Component of Dose Response Uncertainty Scaling Method ($ million/yr)	Species Type ($ million/yr)	Extrapolation Model ($ million/yr)
$p_1=p_2=p_3=0.2$	0.15	0.17	0.12
$p_1=p_2=p_3=0.33$	0.86	1.13	1.15
$p_1=p_2=p_3=0.5$	1.92	2.38	2.46

Section 9

INSIGHTS FROM THE PERCHLOROETHYLENE CASE STUDY

INSIGHTS REGARDING PERCHLOROETHYLENE

In this case study, we have employed the methods of decision analysis to evaluate the risk to human health posed by the use of perchloroethylene in the dry cleaning industry. The evaluation includes an explicit characterization of uncertainty in the relation between the level of PCE exposure and the number of cases of cancer that might be induced. Different assumptions in extrapolation from the meager animal test data now available lead to different projections for human cancer incidence, ranging from about 350 cases per year to about one case every hundred years.

While it may be questioned [2] whether current information supports a finding that PCE should be considered as a human carcinogen for regulatory purposes, on the basis of its acute toxicity alone, it is clear that PCE is clearly a dangerous chemical that can inflict serious damage to human health. Some options for reducing PCE exposure are desirable purely on economic grounds: The savings in costs of PCE more than offsets the cost of better maintenance practices. It is in the interest of the owners and the workers of a dry cleaning establishment and in the interest of the public to implement better maintenance practices throughout the industry. This would result in reductions in PCE exposure by about 40 percent and would reduce operating costs. Additional reductions can be achieved by installing a carbon adsorption "sniffer" unit or using dry-to-dry machines. Such actions might seem prudent to commercial dry cleaning plant owners as a measure to protect workers (in the dry cleaning industry, owners and workers are often the same individuals). Although dry-to-dry machines and adsorption units provide additional health protection for workers and customers, our analysis does not indicate that the health benefits clearly offset the additional costs.

The wide range of uncertainty in the potential incidence of cancer from PCE gives a high value to information that would resolve this uncertainty. The calculation in Section 8 shows that resolving the uncertainty could be worth from one to four million dollars per year, depending on the probabilities assessed on the factors in the dose response extrapolation model. This result justifies additional epidemiological studies and an animal testing program, such as the large-scale bioassays now underway at NCI, to determine the response of several strains of mice and rats to a range of PCE doses. PCE is a chemical whose human exposure is widespread. Given even a very small chance that PCE could induce cancer in humans, it becomes important to discover the carcinogenic potential of PCE. On the other hand, implementation of even a relatively inexpensive control option such as carbon adsorption units implies costs on the order of millions of dollars per year.

INSIGHTS REGARDING THE METHODOLOGY

The determination of whether the risk posed by a toxic chemical is unreasonable generally involves assessment of complex uncertainties. Although we support the use of quantitative estimates, the use of single number estimates such as those put forward by CAG is potentially misleading, for such estimates do not communicate any sense of the uncertainties to nontechnical decision makers. The use of confidence intervals derived from bioassay sample size is particularly misleading, since this source of uncertainty in projecting dose response relationships will often be much less than the uncertainty attending the basis for extrapolating from small animals to humans, the selection of an appropriate animal model, or the mathematical form of the dose response relationship.

Suppressing the uncertainty by invoking prudent assumptions is one basis for regulatory decisions. However, when widely desired products or services are involved and control will require large expenditures, judgments of prudence by scientists may be unacceptable as a means of determining public policy. A superior approach in our opinion is to portray the uncertainty explicitly and incorporate it into the basis for decision. We have illustrated this approach for PCE by calculating cancer incidence not just for one set of assumptions as CAG has done, but for eight alternative sets of assumptions. The methods of decision analysis involve assessment of probabilities over these alternative cases, permitting the calculation of a probability distribution on cancer incidence. By using the methods of cost-benefit analysis, which includes a monetary value on avoiding a case of cancer, one can then determine the best action in the face of uncertainty. Moreover, the decision analysis approach allows the calculation of what it would be worth to resolve the uncertainty. This calculation can be extremely useful for establishing priorities for costly information-gathering activities such as large-scale bioassays.

A frequent criticism of cost-benefit analysis is that distributional effects are suppressed. This case study has included calculation of the health impacts on various affected groups: workers, dry cleaning service users, and persons who live or work in the surrounding community. While we have chosen to value a case of cancer avoided as equal in each group, this assumption can easily be relaxed. Our calculations for PCE show the health impact as falling primarily on the workers and secondarily on the users of coin-operated dry cleaners. The risk to the neighboring public is much smaller by comparison.

The analysis of PCE that we have presented should be viewed as illustrative of a methodology. If such analysis is to be used as a basis for public policy decisions, it should receive review and careful scrutiny from the scientific community through such mechanisms as the EPA Science Advisory Board. Probabilities such as those we have assessed on factors in the dose response relationship should represent a judgment agreed upon by qualified scientists, and the basis for such a judgment should be documented and be available for review.

The decision analysis approach presented in this case study is not necessarily elaborate computationally or expensive to carry out. The largest expense is in assembling the information. We expect that our analysis for PCE could easily be adapted for trichloroethylene (TCE), toluene, or other solvents of concern because of their potential carcinogenicity. We would expect that the conclusions for such analysis would be similar: If there is widespread human exposure and even a small probability that the solvent is a carcinogen, information gathering by means such as large-scale bioassays will have large expected benefits that more than offset the costs.

The analysis presented in this case study was not representative of many substances that are candidates for regulation under TSCA. Human exposure to PCE is well documented. Relatively good data and predictive models for exposure are available. Such information will not be available for new chemicals, especially where complex environmental pathways to people are involved. PCE does not bioaccumulate significantly, whereas many toxic chemicals do. For such chemicals, assessment of uncertainty on human exposure might be as complex as or more complex than the assessment of uncertainty we have presented on the health impacts of PCE.

The PCE case study was also atypical in that it did not involve complex control options or analysis to determine the economic impact of control options. PCE is used directly to provide a consumer service, and control option costs are easily translated into their effect on the cost of dry cleaning. The control options for PCE involved equipment maintenance, purchase of new equipment of a standard kind, and repositioning of equipment. In contrast, many chemicals are used as intermediates in complex manufacturing processes. For these chemicals, one must examine the economics of substitution and the impact of higher prices in a variety of end-use markets. The analytical methods for doing so will be demonstrated in the case study on phthalate esters presented in Part III of this report.

Section 10

REFERENCES

[1] R. E. Albert et al., "The Carcinogen Assessment Group's Carcinogenic Assessment of Tetrachloroethylene (Perchloroethylene)" (1980).

[2] U.S. Environmental Protection Agency, Science Advisory Board, Subcommittee on Airborne Carcinogens. Public meeting held in Washington, D.C., September 4 and 5, 1980. Transcript produced by Neal R. Gross, court reporters and transcribers, Washington, D.C.

[3] "Scientific Basis for Identification of Potential Carcinogens and Estimation of Risks," Federal Register 44 (1979): 39858-39879, and Journal of the National Cancer Institute 63 (1979): 242.

[4] S. J. Mara, E. Suta, and S. S. Lee, Assessment of Human Exposures to Atmospheric Perchloroethylene. Report prepared by SRI for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (1979).

[5] U.S. Department of Commerce, Bureau of the Census, 1974 County Business Patterns.

[6] W. E. Fisher, International Fabricare Institute, Research Division, Silver Spring, Maryland, paper presented at the EPA Hydrocarbon Control Workshop, Chicago, Illinois (July 20, 1977).

[7] Personal communication with Ray McMonigle of Vic Manfacturing, Minneapolis, October 27, 1980.

[8] B. C. McCoy, Study to Support New Source Performance Standards for the Dry Cleaning Industry. Report prepared by TRW for U.S. Environmental Protection Agency, Office of Land Use Planning Standards (1976).

[9] G. E. Anderson et al., Human Exposure to Atmospheric Concentrations of Selected Chemicals. Report prepared by Systems Applications, Inc. for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (1980).

[10] H. R. Ludwig, Occupational Exposure to Perchloroethylene in the Dry Cleaning Industry, draft (Cincinnati: National Institute for Occupational Safety and Health, 1980).

[11] S. J. Mara, "Estimated Population Exposed to Perc from Frequenting Coin-Operated Laundromats Equipped with Dry Cleaning Equipment," memorandum to U.S. Environmental Protection Agency Office of Air Quality Planning and Standards (1979).

[12] Engineering Control Technology Assessment of the Dry Cleaning Industry. Report prepared by Arthur D. Little, Inc., for the National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering (1979).

[13] J. Bumgarner et al., "Coin-Operated Dry Cleaner Study," memorandum prepared by U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory (no date).

[14] S. J. Howie, Ambient Perchloroethylene Levels Inside Coin-Operated Laundries with Dry Cleaning Machines on the Premises. Report prepared by PEDCO Environmental, Inc., for U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory (1980).

[15] Personal communication with Stephen J. Howie of PEDCO Environmental, Inc., Cincinnati, Ohio, February 20, 1981.

[16] F. Pasquill, "The Estimation of the Dispersion of Windborne Material," Meteorological Magazine 90 (1961): 33-49

[17] U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States (1979).

[18] G. F. Evans et al., Measurement of Perchloroethylene in Ambient Air. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory (1979).

[19] C. P. Carpenter, "The Chronic Toxicity of Tetrachloroethylene," Journal of Industrial Hygiene and Toxicology 19 (1937): 323-336.

[20] B. Kylin et al., "Hepatotoxicity of Inhaled Trichloroethylene, Tetrachloroethylene, and Chloroform, Single Exposure." Acta Pharmacologica et Toxicologica 20 (1963): 16-26.

[21] B. Kylin, I Sumegi, and S. Yllner, "Hepatotoxicity of Inhaled Trichloroethylene and Tetrachloroethylene, Long-Term Exposure," Acta Pharmacologica et Toxicologica 22 (1965): 379-385.

[22] C. D. Klaasen and G. L. Plaa, "Relative Effects of Various Chlorinated Hydrocarbons on Liver and Kidney Functions in Mice," Toxicology and Applied Pharmacology 9 (1966): 139-151.

[23] C. D. Klaasen and G. L. Plaa, "Relative Effects of Various Chlorinated Hydrocarbons on Liver and Kidney Function in Dogs," Toxicology and Applied Pharmacology 10 (1967): 119-131.

[24] V. K. Rowe et al., "Vapor Toxicity of Tetrachloroethylene for Laboratory Animals and Human Subjects," Archives of Industrial Hygiene and Occupational Medicine 5 (1952): 566-579.

[25] P. Duprat et al., "Irritant Potency of the Principle Aliphatic Chloride Solvents on the Skin and Ocular Mucous Membranes of Rabbits," European Journal of Toxicology 3 (1976): 171-177.

[26] B. A. Schwetz et al., "The Effect of Maternally Inhaled Trichloroethylene, Perchloroethylene, Methyl Chloroform, and Methylene Chloride on Embryonal and Fetal Development in Mice and Rats," Toxicology and Applied Pharmacology 32 (1975): 84-96.

[27] H. R. Coler and H. R. Rossmiller, "Tetrachloroethylene Exposure in a Small Industry," Archives of Industrial Hygiene and Occupational Medicine 8 (1953): 227-233.

[28] J. P. Hughes, "Hazardous Exposure to Some So-Called Safe Solvents," Journal of the American Medical Association 156 (1954): 234-237.

[29] L. C. Meckler and D. K. Phelps, "Liver Disease Secondary to Tetrachloroethylene--A Case Report," Journal of the American Medical Association 197 (1966): 662-663.

[30] R. D. Stewart, "Acute Tetrachloroethylene Intoxication," Journal of the American Medical Association 208 (1969) 1490-1492.

[31] R. D. Stewart et al., "Human Exposure to Tetrachloroethylene Vapor," Archives of Environmental Health 2 (1961): 516-522.

[32] R. D. Stewart et al., Experimental Human Exposure to Tetrachloroethylene, Archives of Environmental Health 20 (1970): 224-229.

[33] M. Ikeda, "Metabolism of Trichlorethylene and Tetrachloroethylene in Human Subjects," Environmental Health Perspectives 21 (1977): 239-245.

[34] Criteria for a Recommended Standard...Occupational Exposure to Tetrachloroethylene (Perchloroethylene), U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health (1976).

[35] National Cancer Institute, "Bioassay of Tetrachloroethylene for Possible Carcinogenicity," DHEW Publication No. 77-813, U.S. Department of Health, Education, and Welfare, Public Health Service, National Institute of Health (1977).

[36] L. W. Rampy et al., "Results of Long-Term Inhalation Toxicity Studies on Rats of 1,1,1-Trichloroethane and Perchloroethylene Formulations," Proceedings of the First International Congress on Toxicology, ed. Plaa and Duncan, (New York: Academic Press, 1978).

[37] A. Blair, P. Drople, and D. Grarrman, "Causes of Death Among Laundry and Dry Cleaning Workers," American Journal of Public Health 69, no. 5, (1979): 508-511.

[38] R. S. Lin and I. I. Kessler, "A Multifactorial Model for Pancreatic Cancer in Man," Journal of the American Medical Association 245, no. 2, (1981): 147-152.

[39] W. Magard, "In Vitro Bioassay of Chlorinated Hydrocarbon Solvents," unpublished proprietary document for Detrex Chemical Industries, Battelle Laboratories, 1978 (cited in [1]).

[40] Jessie M. Norris, "Assessment of Carcinogenic Potential of Perchloroethylene for Man," paper presented at the 1980 Annual Meeting of the Toxicology Forum, Aspen, Colorado, July 28-August 1, 1980, The Dow Chemical Company, Midland, Michigan, 1980.

[41] "Tetrachloroethylene," IARC Monographs on the Evaluation of the Carcinogenic Rise of Chemicals to Humans, International Agency for Research on Cancer, Lyon, Volume 20, (1979): 491-514.

[42] Environmental Studies Board, National Research Council, National Academy of Sciences, "Carcinogenesis in Man and Laboratory Animals," Pest Control: An Assessment of Present and Alternative Technologies, Vol. 1., National Academy of Sciences, Washington, D.C. (1975): 66-82.

[43] Roy E. Albert et al., "The Carcinogen Assessment Group's Method for Determining the Unit Risk Estimate for Air Pollutants" (1980).

[44] N. Mantel and M. A. Schneiderman, "Estimating 'Safe' Levels, A Hazardous Undertaking," Cancer Research 35, (1975): 1379-86.

[45] The National Research Council, Regulating Pesticides (Washington, D.C.: National Academy of Sciences, 1980).

[46] Food Safety Council, Toward a Better Way to Make Food Safety Decisions (Washington, D.C.: Food Safety Council, 1980).

[47] H. A. Guess and K. Crump, "Can We Use Animal Data to Estimate 'Safe' Doses for Chemical Carcinogens?", Environmental Health: Quantitative Methods. Proceedings of a conference sponsored by SIAM Institute for Mathematics and Society, Alta, Utah, July 5-9, 1976. A. Whittemore, ed., SIAM, Philadelphia, 1977, pp. 13-30.

[48] H. Raiffa, Decisions Analysis, Introductory Lectures on Choices Under Uncertainty (Reading, Mass.: Addison-Wesley, 1970).

[49] C. Holloway, Decision Making Under Uncertainty: Models and Choices (Englewood Cliffs, N.J.: Prentice-Hall, 1979).

[50] D. W. Boyd, D. Cohan, and S. G. Regulinski, Abbreviated RD&D Program Portfolio Selection Workbook. Report prepared by Decision Focus Incorporated for U.S. Department of Energy (1979).

Appendix A

CALCULATING AN ANNUAL CAPITAL CHARGE FOR AN INVESTMENT

To compare annual costs with capital expenditures, either the annual costs need to be converted to net present value or the capital investment needs to be converted to an annual equivalent. The approach taken in this analysis is to convert to annual equivalent. This is done by calculating a capital charge rate (CCR) appropriate for the dry cleaning industry. The annual equivalent of a capital investment is, then:

Annual Equivalent = CCR x Capital Investment of Capital Cost (A.1)

The financial parameters used to calculate the capital charge rate are in Table A-1. The following are the basic assumptions:

- Return on equity is 10 percent above the inflation rate.
- Return on debt is 4 percent above inflation.
- Inflation rate is 8 percent.
- Marginal income tax rate is 17 percent.
- Investment tax credt is 10 percent.
- Tax life of investment is 10 years.
- Book life of investment is 15 years.
- Investment is financed by 25 percent equity and 75 percent debt.
- Property tax and insurance are 2 percent of the value of the investment.

Using these assumptions, the capital charge rate is computed in Table A-2 with the following result:

CCR = 0.097 (A.2)

180

This value is used in the analysis to convert all types of investments to annual equivalents. For a discussion of the equations used in Table A-2, see Appendix B of [50].

Table A-1

DATA FOR CALCULATING THE CAPITAL CHARGE RATE

1. For the market being considered enter the appropriate values for
   - a) return on common equity r_E = 0.18;
   - b) return to preferred equity r_P = ----;
   - c) return to debt r_D = 0.12;
   - d) fraction financed by common equity f_E = 0.25;
   - e) fraction financed by preferred equity f_P = ----;
   - f) fraction financed by debt f_D = 0.75;
   - g) inflation rate inf = 0.08;
   - h) income tax rate TAX = 0.17;

2. Compute
   - a) Current-Dollar After-Tax Cost of Capital (r)

$$r = r_E f_E + r_P f_P + r_D f_D (1 - \mathrm{TAX}) \qquad = 0.120;$$

   - b) Constant-Dollar After-Tax Cost of Capital (r_o)

$$r_o = \frac{r - \mathrm{inf}}{1 + \mathrm{inf}} \qquad = 0.037;$$

Table A-1 (continued)

3. Enter the appropriate values for

   a) current-dollar after-tax cost of capital $r = 0.112$;

   b) constant-dollar after-tax cost of capital $r_o = 0.03$;

   c) inflation rate $inf = 0.08$;

   d) income tax rate $TAX = 0.17$;

   e) investment tax credit rate $ITC = 0.10$;

   f) AFUDC rate (if needed) $a =$ ----;

4. From the process description, enter the appropriate value for

   a) construction lead time $CL = 0$;

   b) property tax and insurance $PTI = 0.02$;

   c) tax life $TL = 10$;

   d) book life $BL = 15$;

Table A-2

CALCULATION OF THE CAPITAL CHARGE RATE

1. Compute the present value factors:

a) $PV(r_o,BL) = \frac{1}{r_o}\left\{1 - \frac{1}{1+r_o} BL\right\}$ = 11.36;

b) $PV(r,BL) = \frac{1}{r}\left\{1 - \frac{1}{1+r} BL\right\}$ = 6.81;

c) $PV(r,TL) = \frac{1}{r}\left\{1 - \frac{1}{1+r} TL\right\}$ = 5.65;

d) $D(inf, CL) = \left\{\frac{1}{1+inf}\right\}^{CL/3}$ = 1.0;

2. Compute appropriate construction cost financing and tax factors:

	Regulated Utility	Unregulated Industry	
a)	$\left\{\frac{1+a}{1+inf}\right\}^{CL/3}$	$\left\{\frac{1+r}{1+inf}\right\}^{CL/3}$	= 1.0;
b)	$\frac{TAX \times D(inf,CL)}{TL} PV(r,TL)$	same as utility	= 0.096;
c)	$\frac{ITC \times D(inf,CL)}{1+r}$	$ITC \left\{\frac{1+r}{1+inf}\right\}^{CL/3}$	= 0.10;
d)	$PTI(1-TAX)PV(r,BL)D(inf,CL)$	same as utility	= 0.113;

3. Compute Effective Capital Cost Factor:

(line 2a) - (line 2b) - (line 2c) + (line 2d) = ECCF = 0.917;

4. Compute Capital Charge Rate:

$CCR = \frac{1}{1-TAX} \; \frac{1}{PV(r_o,BL)} \; ECCF$ = 0.097;

Appendix B

DETAILED CALCULATIONS OF CONTROL COSTS AND EXPOSURE REDUCTION

CONTROL OPTION COMPUTATIONS

Option Number	Description
1	Implement better maintenance and housekeeping in all commercial and industrial plants.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.059	0.038	0.136
Fraction	0.60	0.67	1.0
kg of cleaning	900×10^6	110×10^6	400×10^6
PCE consumption	50×10^6	6×10^6	54×10^6

Total Emission Fraction 110/152 = 0.72

Multipliers for Service Users

Commercial Dry Cleaning	0.56
Coin-Operated Dry Cleaning	1.00
Coin-Operated Laundry	1.00

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	0	0	0
Maintenance	525	2850	0
PCE credit	-1200	-4340	0
Total	- 675	-1490	0
Number of plants	16,000	350	11,000
Total dollars	-10.8×10^6	-0.5×10^6	0

Total Cost = -11.3 million dollars per year

Option Analysis

Option Number	Description
2	Implement better maintenance and housekeeping in all coin-operated dry cleaners.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.099	0.056	0.075
Fraction	1.0	1.0	0.55
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	89×10^6	9×10^6	30×10^6

Total Emission Fraction 128/152 = 0.84

Multipliers for Service Users

Commercial Dry Cleaning	1.00
Coin-Operated Dry Cleaning	0.59
Coin-Operated Laundry	0.55

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	0	0	0
Maintenance	0	0	975
PCE credit	0	0	-1177
Total	0	0	- 202
Number of plants	16,000	350	11,000
Total dollars	0	0	-2.2×10^6

Total Cost = -2.2 million dollars per year

Option Analysis

Option Number	Description
3	Install carbon adsorber units in all commercial and industrial plants that do not already have them.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.080	0.054	0.136
Fraction	0.81	0.96	1.0
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	72×10^6	9×10^6	54×10^6

Total Emission Fraction 135/152 = 0.89

Multipliers for Service Users

Commercial Dry Cleaning	0.89
Coin-Operated Dry Cleaning	1.00
Coin-Operated Laundry	1.00

B. COSTS

Item	Commercial*	Industrial**	Coin-Op
Capital	243	88	0
Maintenance	125	46	0
PCE credit	-570	-480	0
Total	-202	-346	0
Number of plants	16,000	350	11,000
Total dollars	-3.2×10^6	-0.1×10^6	

Total Cost = -3.3 million dollars per year

---

*Average cost per plant, 50% of plants have expense.
**Average cost per plant, 10% of plants have expense.

Option Analysis

Option Number	Description
4	Install carbon adsorber units in all coin-operated plants that do not already have them.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.099	0.056	0.109
Fraction	1.0	1.0	0.67
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	89×10^6	9×10^6	44×10^6

Total Emission Fraction 143/152 = 0.93

Multipliers for Service Users

Commercial Dry Cleaning	1.00
Coin-Operated Dry Cleaning	0.74
Coin-Operated Laundry	0.67

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	0	0	354
Maintenance	0	0	183
PCE credit	0	0	-512
Total	0	0	24
Number of plants	16,000	350	11,000
Total dollars	0	0	0.3×10^6

Total Cost = 0.3 million dollars per year

Option Analysis

Option Number	Description
5	Replace all transfer type cleaning machines in commercial plants with dry-to-dry units as the machines normally need to be replaced.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.099	0.056	0.136
Fraction	1.0	1.0	1.0
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	89×10^6	9×10^6	54×10^6

Total Emission Fraction 152/152 = 1.0

Multiply exposure to commercial machine operators by 0.66

Multipliers for Service Users

Commercial Dry Cleaning	1.00
Coin-Operated Dry Cleaning	1.00
Coin-Operated Laundry	1.00

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	545	0	0
Maintenance	0	0	0
PCE credit	0	0	0
Total	545	0	0
Total dollars	8.7×10^6	0	0

Total Cost = 8.7 million dollars per year

Option Analysis

Option Number	Description
6	Move all coin-operated dry cleaning machines to rooms separate from laundry.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.099	0.056	0.136
Fraction	1.0	1.0	1.0
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	89×10^6	9×10^6	54×10^6

Total Emission Fraction 152/152 = 1.0

Multipliers for Service Users

Commercial Dry Cleaning	1.00
Coin-Operated Dry Cleaning	1.00
Coin-Operated Laundry	0.10

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	0	0	445
Maintenance	0	0	0
PCE credit	0	0	0
Total	0	0	445
Number of plants	16,000	350	11,000
Total dollars	0	0	4.9×10^6

Total Cost = 4.9 million dollars per year

Option Analysis

Option Number	Description
7	Options 1 and 2.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.059	0.038	0.075
Fraction	0.60	0.67	0.55
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	50×10^6	6×10^6	30×10^6

Total Emission Fraction 86/152 = 0.57

Multipliers for Service Users

Commercial Dry Cleaning	0.56
Coin-Operated Dry Cleaning	0.59
Coin-Operated Laundry	0.55

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	0	0	0
Maintenance	525	2850	975
PCE credit	-1200	-4340	-1177
Total	- 675	-1490	- 202
Number of plants	16,000	350	11,000
Total dollars	-10.8×10^6	-0.5×10^6	-2.2×10^6

Total Cost = -13.5 million dollars per year

Option Analysis

Option Number	Description
8	Options 1, 2, and 3.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.048	0.036	0.075
Fraction	0.49	0.64	0.55
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	30×10^6

Total Emission Fraction 79/152 = 0.52

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.59
Coin-Operated Laundry	0.55

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	243	88	0
Maintenance	650	2896	975
PCE credit	-1530	-4800	-1177
Total	- 637	-1816	- 202
Number of plants	16,000	350	11,000
Total dollars	-10.2×10^6	-0.6×10^6	-2.2×10^6

Total Cost = -13.0 million dollars per year

Option Analysis

Option Number	Description
9	Options 1, 2, 3, and 4.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.048	0.036	0.060
Fraction	0.49	0.64	0.44
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	24×10^6

Total Emission Fraction 73/152 = 0.48

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.50
Coin-Operated Laundry	0.44

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	243	88	354
Maintenance	650	2896	1158
PCE credit	-1530	-4800	-1444
Total	- 637	-1816	68
Number of plants	16,000	350	11,000
Total dollars	-10.2×10^6	-0.6×10^6	0.7×10^6

Total Cost = -10.1 million dollars per year

Option Analysis

Option Number	Description
10	Options 1, 2, 3, and 5.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.048	0.036	0.075
Fraction	0.49	0.64	0.55
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	30×10^6

Total Emission Fraction 79/152 = 0.52

Multiply exposure to commercial machine operators by 0.49 x 0.66 = 0.32

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.59
Coin-Operated Laundry	0.55

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	788	88	0
Maintenance	650	2896	975
PCE credit	-1530	-4800	-1177
Total	- 92	-1816	- 202
Number of plants	16,000	350	11,000
Total dollars	-1.5×10^6	-0.6×10^6	-2.2×10^6

Total Cost = -4.3 million dollars per year

194

Option Analysis

Option Number	Description
11	Options 1, 2, 3, and 6.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.048	0.036	0.075
Fraction	0.49	0.64	0.55
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	30×10^6

Total Emission Fraction 79/152 = 0.52

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.59
Coin-Operated Laundry	0.055

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	243	88	445
Maintenance	650	2896	975
PCE credit	-1530	-4800	-1177
Total	- 637	-1816	243
Number of plants	16,000	350	11,000
Total dollars	-10.2×10^6	-0.6×10^6	2.7×10^6

Total Cost = -8.1 million dollars per year

Option Analysis

Option Number	Description
12	Options 1, 2, 3, 4, and 5.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.048	0.036	0.060
Fraction	0.49	0.64	0.44
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	24×10^6

Total Emission Fraction 73/152 = 0.48

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.50
Coin-Operated Laundry	0.44

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	788	88	354
Maintenance	650	2896	1158
PCE credit	-1530	-4800	-1444
Total	- 92	-1816	68
Number of plants	16,000	350	11,000
Total dollars	-1.5×10^6	-0.6×10^6	0.7×10^6

Total Cost = -1.4 million dollars per year

Option Analysis

Option Number	Description
13	Options 1, 2, 3, 4, and 6.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.048	0.036	0.060
Fraction	0.49	0.64	0.44
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	24×10^6

Total Emission Fraction 73/152 = 0.48

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.50
Coin-Operated Laundry	0.044

B. COSTS

Costs	Commercial	Industrial	Coin-Op
Capital	243	88	799
Maintenance	650	2896	1158
PCE credit	-1530	-4800	-1444
Total	- 637	-1816	513
Number of plants	16,000	350	11,000
Total dollars	-10.2×10^6	-0.6×10^6	5.6×10^6

Total Cost = -5.2 million dollars per year

Option Analysis

Option Number	Description
14	Options 1, 2, 3, 5, and 6.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.048	0.036	0.075
Fraction	0.49	0.64	0.55
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	30×10^6

Total Emission Fraction 79/152 = 0.52

Multiply exposure to commercial machine operators by 0.32

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.59
Coin-Operated Laundry	0.055

B. COSTS

Costs	Commercial	Industrial	Coin-Op
Capital	788	88	445
Maintenance	650	2896	975
PCE credit	-1530	-4800	-1177
Total	- 92	-1816	243
Number of plants	16,000	350	11,000
Total dollars	-1.5×10^6	-0.6×10^6	2.7×10^6

Total Cost = 0.6 million dollars per year

Option Analysis

Option Number	Description
15	Options 1, 2, 3, 4, 5, and 6.

A. EMISSIONS

Item	Commercial	Industrial	Coin-Op
Base emission rate	0.099	0.056	0.136
Rate after option	0.043	0.036	0.060
Fraction	0.49	0.64	0.44
kg of cleaning	900×10^6	160×10^6	400×10^6
PCE consumption	43×10^6	6×10^6	24×10^6

Total Emission Fraction 73/152 = 0.48

Multiply exposure to commercial machine operators by 0.32

Multipliers for Service Users

Commercial Dry Cleaning	0.49
Coin-Operated Dry Cleaning	0.50
Coin-Operated Laundry	0.044

B. COSTS

Item	Commercial	Industrial	Coin-Op
Capital	788	88	799
Maintenance	650	2896	1158
PCE credit	-1530	-4800	-1444
Total	-92	-1816	513
Number of plants	16,000	350	11,000
Total dollars	-1.5×10^6	-0.6×10^6	5.6×10^6

Total Cost = 3.5 million dollars per year

199

Appendix C

CALCULATIONS OF PROBABILITY OF INCIDENCE AND EXPECTED CANCER CASES BY CONTROL OPTION AND DOSE RESPONSE CASE

The calculations of lifetime cancer incidence in humans resulting from doses of PCE are outlined in this appendix. The detailed computed results for cancer incidence by exposure category follow.

ANIMAL DATA

From Chapter 6, the observed cancer incidence in mice and rats are taken to be

1. Incidence of 0.65 in mice at a lifetime dose of 332 mg/kg/day. We followed the practice used by CAG ([1],p.24) in considering the dose of 536 miligrams/kilogram/day for five days per week over 78 weeks as equivalent to an average lifetime dose of 536 x 5/7 x (78/90) = 332 miligrams/kilogram/day.
2. Incidence of 0.05 in rats at a lifetime dose of 253 mg/kg/day.

EXTRAPOLATION BY BODY WEIGHT

In extrapolating from animals to humans by body weight, dosages in miligrams of PCE per kilogram of body weight are considered equivalent. Therefore, it is assumed that

1. If the mouse is chosen as the representative species, then a dose of 332 mg/kg/day would result in a lifetime cancer incidence of 0.65 in humans.
2. If the rat is chosen as the representative species, then a dose of 253 mg/kg/day would result in a lifetime cancer incidence of 0.05 in humans.

EXTRAPOLATION BY SURFACE AREA

In extrapolating by surface area, equivalent doses in different sized animals are adjusted by the cube root of the ratio of body weights as follows:

1. In extrapolating from mice to humans, the scaling factor is

$$\left(\frac{70}{0.03}\right)^{1/3} = 13.26$$

A dose of 332 mg/kg/day for mice is considered to be equivalent to 332/13.26 = 25.0 mg/kg/day for humans.

2. In extrapolating from rats to humans, the scaling factor is

$$\left(\frac{70}{0.35}\right)^{1/3} = 5.85$$

A dose of 253 mg/kg/day for rats is considered to be equivalent to 253/5.85 = 43.3 mg/kg/day for humans.

EXTRAPOLATION WITH A LINEAR MODEL

The linear model for predicting cancer indidence as a function of dose level is

$$P(d) = 1 - \exp(-\lambda d) \qquad \lambda > 0 \qquad \text{(C.1)}$$

where P(d) is the lifetime probability of cancer occurrence given a dose level d, and λ is a coefficient that must be estimated. The model is called linear because incidence is proportional to dose at low doses.

Rewriting (C.1), the coefficient λ can be found by

$$\lambda = \frac{-\ln(1 - P(d))}{d} \qquad \text{(C.2)}$$

Using (C.2), λ is calculated as follows:

1. Using mouse data and extrapolation by body weight

$$\lambda = \frac{-\ln(1 - 0.65)}{332} = 0.00316$$

2. Using mouse data and extrapolation by surface area

$$\lambda = \frac{-\ln(1 - 0.65)}{25.0} = 0.0419$$

3. Using rat data and extrapolation by body weight

$$\lambda = \frac{-\ln(1 - 0.05)}{253} = 0.000203$$

4. Using rat data and extrapolation by surface area

$$\lambda = \frac{-\ln(1 - 0.5)}{43.3} = 0.00119$$

EXTRAPOLATION WITH A QUADRATIC MODEL

The quadratic model for predicting cancer incidence as a function of dose level is

$$P(d) = 1 - \exp(-\lambda d^2) \qquad \lambda > 0 \tag{C.3}$$

Rewriting to solve for the coefficient λ gives

$$\lambda = \frac{-\ln(1 - P(d))}{d^2} \tag{C.4}$$

Using (C.4) and the same doses and incidence probabilities as in the calculations for the linear model, λ is calculated as follows:

1. Using mouse data and extropolation by body weight,

   $\lambda = 9.52 \times 10^{-6}$

2. Using mouse data and extropolation by surface area,

   $\lambda = 0.00167$

3. Using rat data and extrapolation by body weight,

   $\lambda = 8.01 \times 10^{-7}$

4. Using rat data and extrapolation by surface area,

   $\lambda = 2.74 \times 10^{-5}$

EXPECTED ANNUAL CANCER CASES

The expected annual number of cancer cases is taken to be the number of people exposed times the expected lifetime incidence divided by an average life span of 70 years.

```
                       BASE CASE

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime        Expected
     Type of                  Number in              Average Annual Exposure         Incidence          Annual Cases
     Person                U. S. Population   (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                ----------------   -------------------    -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.             45000.               6.43           0.2363              54.02
    Industrial                     700.             45000.               6.43           0.2363               2.36
    Coin-Op                      11000.              6000.             0.8571           0.0353               5.55

Other Workers
-------------
    Commercial                  110000.             10000.               1.43           0.0582              91.39
    Industrial                   20000.             10000.               1.43           0.0582              16.62
    Coin-Op                      22000.              6000.             0.8571           0.0353              11.10

Service Users
-------------
    Commercial Dry Clean      50000000.               5.00           0.000714        2.998E-05              21.42
    Coin-Op Dry Clean         25000000.              10.00           0.001429        5.990E-05              21.39
    Coin-Op Laundry           37000000.              38.00           0.005429         0.000228              120.

Urban Residents
---------------
      25 -  200 *              3700000.               3.50           0.000500        2.098E-05               1.11
     200 -  500 *             20000000.             0.6000          8.571E-05        3.595E-06               1.03
     500 - 1000 *             71000000.             0.2000          2.857E-05        1.198E-06               1.22
                                                                                                      -------------
* Distance from dry cleaner in meters                                                    Total             348.

Total cost of option and expected cancer (millions of dollars) =    347.51
```

```
                    BASE CASE

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =       0.001675
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime       Expected
   Type of                    Number in            Average Annual Exposure            Incidence          Annual Cases
   Person                  U. S. Population  (micro gms/cubic m)      (mg/kg/day)  (probability/lifetime)  (number/year)
   ------                  ----------------  -------------------      -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.            45000.                  6.43             0.0669            15.29
    Industrial                     700.            45000.                  6.43             0.0669            0.6690
    Coin-Op                      11000.             6000.                0.8571           0.001230            0.1933

Other Workers
-------------
    Commercial                  110000.            10000.                  1.43           0.003413              5.36
    Industrial                   20000.            10000.                  1.43           0.003413            0.9753
    Coin-Op                      22000.             6000.                0.8571           0.001230            0.3866

Service Users
-------------
    Commercial Dry Clean      50000000.              5.00              0.000714          8.548E-10          0.000611
    Coin-Op Dry Clean         25000000.             10.00              0.001429          3.419E-09          0.001221
    Coin-Op Laundry           37000000.             38.00              0.005429          4.937E-08            0.0261

Urban Residents
---------------
     25 -  200 *               3700000.              3.50              0.000500          4.189E-10         2.214E-05
    200 -  500 *              20000000.            0.6000             8.571E-05          1.231E-11         3.517E-06
    500 - 1000 *              71000000.            0.2000             2.857E-05          1.368E-12         1.387E-06
                                                                                                       -------------
* Distance from dry cleaner in meters                                                       Total           22.91

Total cost of option and expected cancer (millions of dollars) =     22.91
```

```
                    BASE CASE

Scaling: SURFACE_AREA   Species:   RAT   Model:    LINEAR
Response of  5 percent corresponds to dose in man of   43,3 mg/kg/day which implies lambda =      0,001186
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1,00

                                                                              Expected Lifetime        Expected
      Type of                     Number in          Average Annual Exposure       Incidence           Annual Cases
      Person                   U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
      ------                   ----------------  -------------------     -----------   ---------------------   ------------

Machine Operators
-----------------
    Commercial                      16000.             45000.                 6,43          0,007593                1,74
    Industrial                        700.             45000.                 6,43          0,007593              0,0759
    Coin-Op                         11000.              6000.               0,8571          0,001016              0,1596

Other Workers
-------------
    Commercial                     110000.             10000.                 1,43          0,001692                2,66
    Industrial                      20000.             10000.                 1,43          0,001692              0,4835
    Coin-Op                         22000.              6000.               0,8571          0,001016              0,3192

Service Users
-------------
    Commercial Dry Clean         50000000.               5,00             0,000714          8,469E-07             0,6049
    Coin-Op Dry Clean            25000000.              10,00             0,001429          1,694E-06             0,6049
    Coin-Op Laundry              37000000.              38,00             0,005429          6,436E-06               3,40

Urban Residents
---------------
     25 -  200 *                  3700000.               3,50             0,000500          5,928E-07             0,0313
    200 -  500 *                 20000000.             0,6000            8,571E-05          1,016E-07             0,0290
    500 - 1000 *                 71000000.             0,2000            2,857E-05          3,387E-08             0,0344
                                                                                                              ------------
                                                                                                 Total            10,14
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     10,14
```

```
                  BASE CASE

Scaling:  SURFACE_AREA    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime         Expected
    Type of                     Number in             Average Annual Exposure           Incidence          Annual Cases
    Person                 U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                 ----------------  -------------------     -----------   ---------------------  -------------

Machine Operators
-----------------
    Commercial                  16000.             45000.                6.43            0.001132              0.2587
    Industrial                    700.             45000.                6.43            0.001132              0.0113
    Coin-Op                     11000.              6000.              0.8571           2.015E-05            0.003166

Other Workers
-------------
    Commercial                 110000.             10000.                1.43           5.591E-05              0.0879
    Industrial                  20000.             10000.                1.43           5.591E-05              0.0160
    Coin-Op                     22000.              6000.              0.8571           2.015E-05            0.006332

Service Users
-------------
    Commercial Dry Clean     50000000.               5.00            0.000714           1.398E-11          9.987E-06
    Coin-Up Dry Clean        25000000.              10.00            0.001429           5.593E-11          1.997E-05
    Coin-Op Laundry          37000000.              36.00            0.005429           8.076E-10           0.000427

Urban Residents
---------------
     25 -  200 *              3700000.               3.50            0.000500           6.851E-12          3.621E-07
    200 -  500 *             20000000.             0.6000           8.571E-05           2.013E-13          5.753E-08
    500 - 1000 *             71000000.             0.2000           2.857E-05           2.237E-14          2.269E-08
                                                                                                         -------------
                                                                                          Total               0.3836
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      0.38
```

```
                         BASE CASE

Scaling:   BODY_WEIGHT    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1.00

                                                                             Expected Lifetime        Expected
     Type of                   Number in          Average Annual Exposure         Incidence         Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------    -----------  ----------------------  ------------

Machine Operators
-----------------
     Commercial                   16000.            45000.              6.43          0.0201              4.60
     Industrial                     700.            45000.              6.43          0.0201            0.2012
     Coin-Op                      11000.             6000.            0.8571        0.002707            0.4253

Other Workers
-------------
     Commercial                  110000.            10000.              1.43        0.004507              7.08
     Industrial                   20000.            10000.              1.43        0.004507              1.29
     Coin-Op                      22000.             6000.            0.8571        0.002707            0.8507

Service Users
-------------
     Commercial Dry Clean      50000000.              5.00          0.000714       2.259E-06              1.61
     Coin-Op Dry Clean         25000000.             10.00          0.001429       4.517E-06              1.61
     Coin-Op Laundry           37000000.             38.00          0.005429       1.717E-05              9.07

Urban Residents
---------------
      25 -  200 *               3700000.              3.50          0.000500       1.581E-06            0.0836
     200 -  500 *              20000000.            0.6000         8.571E-05       2.710E-07            0.0774
     500 - 1000 *              71000000.            0.2000         2.857E-05       9.035E-08            0.0916
                                                                                                  ------------
* Distance from dry cleaner in meters                                                  Total             27.00

Total cost of option and expected cancer (millions of dollars) =     27.00
```

```
                          BASE CASE

Scaling:  BODY_WEIGHT    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1.00

   Type of                                                                     Expected Lifetime      Expected
   Person                  Number in           Average Annual Exposure            Incidence         Annual Cases
   ------               U. S. Population   (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime) (number/year)
                        ----------------   -------------------    -----------  ---------------------- -------------
Machine Operators
-----------------
   Commercial               16000.              45000.               6.43          0.000394            0.0899
   Industrial                 700.              45000.               6.43          0.000394          0.003935
   Coin-Op                  11000.               6000.             0.8571         6.998E-06          0.001100
Other Workers
-------------
   Commercial              110000.              10000.               1.43         1.943E-05            0.0305
   Industrial               20000.              10000.               1.43         1.943E-05          0.005552
   Coin-Op                  22000.               6000.             0.8571         6.998E-06          0.002199
Service Users
-------------
   Commercial Dry Clean  50000000.                5.00           0.000714         4.859E-12         3.471E-06
   Coin-Op Dry Clean     25000000.               10.00           0.001429         1.944E-11         6.942E-06
   Coin-Op Laundry       37000000.               38.00           0.005429         2.807E-10          0.000148
Urban Residents
---------------
     25 -  200 *          3700000.                3.50           0.000500         2.381E-12         1.259E-07
    200 -  500 *         20000000.              0.6000          8.571E-05         6.998E-14         1.999E-08
    500 - 1000 *         71000000.              0.2000          2.857E-05         7.775E-15         7.686E-09
                                                                                                 -------------
* Distance from dry cleaner in meters                                                  Total         0.1334

Total cost of option and expected cancer (millions of dollars) =      0.13
```

```
                       BASE CASE

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =        0.000203
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
      Type of                     Number in           Average Annual Exposure       Incidence          Annual Cases
      Person                  U. S. Population  (micro gms/cubic m)   (mg/kg/day)  (probability/lifetime) (number/year)
      ------                  ----------------  -------------------   -----------  ---------------------- -------------

Machine Operators
-----------------
     Commercial                     16000.            45000.             6,43           0,001302             0,2977
     Industrial                       700.            45000.             6,43           0,001302             0,0130
     Coin-Op                        11000.             6000.           0,8571           0,000174             0,0273

Other Workers
-------------
     Commercial                    110000.            10000.             1,43           0.000290             0,4550
     Industrial                     20000.            10000.             1,43           0,000290             0,0627
     Coin-Op                        22000.             6000.           0,8571           0.000174             0,0546

Service Users
-------------
     Commercial Dry Clean        50000000.             5.00          0,000714           1,448E-07            0,1034
     Coin-Op Dry Clean           25000000.            10.00          0,001429           2,896E-07            0,1034
     Coin-Op Laundry             37000000.            38.00          0,005429           1.101E-06            0,5817

Urban Residents
---------------
      25 -  200 *                 3700000.             3.50          0.000500           1.014E-07          0,005358
     200 -  500 *                20000000.           0.6000          8.571E-05          1,738E-08          0,004965
     500 - 1000 *                71000000.           0.2000          2.857E-05          5.793E-09          0,005875
                                                                                                         -------------
                                                                                         Total               1.74
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      1,74
```

```
                         BASE CASE

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) =  0.00  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime        Expected
     Type of                   Number in           Average Annual Exposure        Incidence         Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                   16000.             45000.              6.43          3.314E-05            0.007575
     Industrial                     700.             45000.              6.43          3.314E-05            0.000331
     Coin-Op                      11000.              6000.            0.8571          5.887E-07           9.252E-05

Other Workers
-------------
     Commercial                  110000.             10000.              1.43          1.635E-06            0.002570
     Industrial                   20000.             10000.              1.43          1.635E-06            0.000467
     Coin-Op                      22000.              6000.            0.8571          5.887E-07            0.000185

Service Users
-------------
     Commercial Dry Clean      50000000.               5.00          0.000714          4.088E-13           2.920E-07
     Coin-Op Dry Clean         25000000.              10.00          0.001429          1.635E-12           5.841E-07
     Coin-Up Laundry           37000000.              38.00          0.005429          2.362E-11           1.248E-05

Urban Residents
---------------
      25 -  200 *               3700000.               3.50          0.000500          2.003E-13           1.059E-08
     200 -  500 *              20000000.             0.6000         8.571E-05          5.887E-15           1.662E-09
     500 - 1000 *              71000000.             0.2000         2.857E-05          6.542E-16           6.635E-10
                                                                                                       -------------
                                                                                          Total             0.0112
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      0.01
```

```
                              OPTION 1

Scaling: SURFACE_AREA    Species: MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0,0419
Option cost (millions of dollars) =-11,30  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime      Expected
      Type of                      Number in          Average Annual Exposure     Incidence         Annual Cases
      Person                    U. S. Population  (micro gms/cubic m)   (mg/kg/day)  (probability/lifetime)  (number/year)
      ------                    ----------------  -------------------   -----------  ----------------------  ------------

Machine Operators
-----------------
    Commercial                       16000.            27000.              3,86            0,1494              34,14
    Industrial                         700.            30150.              4,31            0,1653               1,65
    Coin-Op                          11000.             6000.            0,8571            0,0353               5,55

Other Workers
-------------
    Commercial                      110000.             6000.            0,8571            0,0353              55,49
    Industrial                       20000.             6700.            0,9571            0,0393              11,24
    Coin-Op                          22000.             6000.            0,8571            0,0353              11,10

Service Users
-------------
    Commercial Dry Clean          50000000.             2,80           0,000400         1,675E-05             11,96
    Coin-Op Dry Clean             25000000.            10,00           0,001429         5,990E-05             21,39
    Coin-Op Laundry               37000000.            38,00           0,005429          0,000228              120.

Urban Residents
---------------
     25 -  200 *                   3700000.             2,52           0,000360         1,508E-05             0,7971
    200 -  500 *                  20000000.           0,4320          6,171E-05         2,588E-06             0,7395
    500 - 1000 *                  71000000.           0,1440          2,057E-05         8,628E-07             0,8751
                                                                                                          ------------
                                                                                          Total              275.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    263,96
```

```
                         OPTION 1

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =      0.001675
Option cost (millions of dollars) =-11.30  Cost per cancer case (millions of dollars) =  1.00

    Type of                              Number in                 Average Annual Exposure              Expected Lifetime          Expected
    Person                          U. S. Population     (micro gms/cubic m)        (mg/kg/day)              Incidence           Annual Cases
    ------                          ----------------     -------------------        -----------      (probability/lifetime)     (number/year)
                                                                                                     ----------------------     -------------
Machine Operators
-----------------
      Commercial                           16000.               27000.                   3.86               0.0246                  5.63
      Industrial                             700.               30150.                   4.31               0.0306                0.3060
      Coin-Op                              11000.                6000.                 0.8571             0.001230                0.1933
Other Workers
-------------
      Commercial                          110000.                6000.                 0.8571             0.001230                  1.93
      Industrial                           20000.                6700.                 0.9571             0.001534                0.4382
      Coin-Op                              22000.                6000.                 0.8571             0.001230                0.3866
Service Users
-------------
      Commercial Dry Clean             50000000.                 2.80               0.000400            2.681E-10
      Coin-Op Dry Clean                25000000.                10.00               0.001429            3.419E-09             0.000191
      Coin-Op Laundry                  37000000.                38.00               0.005429            4.937E-08             0.001221
                                                                                                                                  0.0261
Urban Residents
---------------
       25 -  200 *                      3700000.                 2.52               0.000360            2.171E-10            1.148E-05
      200 -  500 *                     20000000.               0.4320              6.171E-05            6.381E-12            1.823E-06
      500 - 1000 *                     71000000.               0.1440              2.057E-05            7.090E-13            7.192E-07
                                                                                                                        -------------
* Distance from dry cleaner in meters                                                                     Total                 8.91

Total cost of option and expected cancer (millions of dollars) =      -2.39
```

```
                    OPTION 1

Scaling: SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) =-11.30  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime        Expected
    Type of                    Number in           Average Annual Exposure        Incidence          Annual Cases
    Person                  U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                  ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.            27000.                3.86          0.004563                1.04
    Industrial                     700.            30150.                4.31          0.005094                0.0509
    Coin-Op                      11000.             6000.                0.6571        0.001016                0.1596

Other Workers
-------------
    Commercial                  110000.             6000.                0.8571        0.001016                1.60
    Industrial                   20000.             6700.                0.9571        0.001134                0.3240
    Coin-Up                      22000.             6000.                0.8571        0.001016                0.3192

Service Users
-------------
    Commercial Dry Clean      50000000.               2.80               0.000400      4.742E-07               0.3387
    Coin-Op Dry Clean         25000000.              10.00               0.001429      1.694E-06               0.6049
    Coin-Op Laundry           37000000.              38.00               0.005429      6.436E-06               3.40

Urban Residents
---------------
     25 -  200 *               3700000.               2.52               0.000360      4.268E-07               0.0226
    200 -  500 *              20000000.               0.4320             6.171E-05     7.317E-08               0.0209
    500 - 1000 *              71000000.               0.1440             2.057E-05     2.439E-08               0.0247
                                                                                                           -------------
                                                                                       Total                   7.91
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      -3.39
```

213

```
                                  OPTION 1

Scaling: SURFACE_AREA    Species:   RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =-11.30  Cost per cancer case (millions of dollars) =  1.00

      Type of                                                                          Expected Lifetime        Expected
      Person                      Number in              Average Annual Exposure           Incidence          Annual Cases
      ------                  U. S. Population   (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
                              ----------------   -------------------     -----------  ----------------------  -------------
  Machine Operators
  -----------------
      Commercial                    16000.               27000.               3.86          0.000408              0.0932
      Industrial                      700.               30150.               4.31          0.000508            0.005082
      Coin-Op                       11000.                6000.             0.8571         2.015E-05            0.003166
  Other Workers
  -------------
      Commercial                   110000.                6000.             0.8571         2.015E-05              0.0317
      Industrial                    20000.                6700.             0.9571         2.509E-05            0.007170
      Coin-Op                       22000.                6000.             0.8571         2.015E-05            0.006332
  Service Users
  -------------
      Commercial Dry Clean      50000000.                 2.80           0.000400         4.385E-12           3.132E-06
      Coin-Op Dry Clean         25000000.                10.00           0.001429         5.593E-11           1.997E-05
      Coin-Op Laundry           37000000.                38.00           0.005429         8.076E-10            0.000427
  Urban Residents
  ---------------
       25 -  200 *               3700000.                 2.52           0.000360         3.552E-12           1.877E-07
      200 -  500 *              20000000.               0.4320          6.171E-05         1.044E-13           2.982E-08
      500 - 1000 *              71000000.               0.1440          2.057E-05         1.160E-14           1.176E-08
                                                                                                          -------------
  * Distance from dry cleaner in meters                                                      Total              0.1470

  Total cost of option and expected cancer (millions of dollars) =    -11.15
```

```
                  OPTION 1

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      0.003162
Option cost (millions of dollars) =-11.30  Cost per cancer case (millions of dollars) =  1.00

                                                                            Expected Lifetime       Expected
      Type of                       Number in          Average Annual Exposure          Incidence           Annual Cases
      Person                     U. S. Population  (micro gms/cubic m)      (mg/kg/day)    (probability/lifetime)  (number/year)
      ------                     ---------------   ------------------       ----------    ---------------------  ------------

Machine Operators
-----------------
    Commercial                        16000.              27000.              3.86              0.0121              2.77
    Industrial                          700.              30150.              4.31              0.0135            0.1353
    Coin-Op                           11000.               6000.            0.8571            0.002707            0.4253

Other Workers
-------------
    Commercial                       110000.               6000.            0.8571            0.002707              4.25
    Industrial                        20000.               6700.            0.9571            0.003022            0.6634
    Coin-Op                           22000.               6000.            0.8571            0.002707            0.8507

Service Users
-------------
    Commercial Dry Clean           50000000.               2.80           0.000400           1.265E-06            0.9035
    Coin-Op Dry Clean              25000000.              10.00           0.001429           4.517E-06              1.61
    Coin-Op Laundry                37000000.              38.00           0.005429           1.717E-05              9.07

Urban Residents
---------------
     25 -  200 *                    3700000.               2.52           0.000360           1.138E-06            0.0602
    200 -  500 *                   20000000.             0.4320          6.171E-05           1.951E-07            0.0558
    500 - 1000 *                   71000000.             0.1440          2.057E-05           6.505E-08            0.0660
                                                                                                             ------------
                                                                                              Total                21.07
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      9.77
```

```
                         OPTION 1

Scaling:  BODY_WEIGHT   Species:  MOUSE   Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =     9.524E-06
Option cost (millions of dollars) =-11.30  Cost per cancer case (millions of dollars) =  1.00

                                                                             Expected Lifetime        Expected
    Type of                  Number in           Average Annual Exposure        Incidence          Annual Cases
    Person               U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
    ------               ----------------  -------------------   -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                16000.            27000.             3.86           0.000142              0.0324
    Industrial                  700.            30150.             4.31           0.000177            0.001767
    Coin-Op                   11000.             6000.           0.8571          6.998E-06            0.001100

Other Workers
-------------
    Commercial               110000.             6000.           0.8571          6.998E-06              0.0110
    Industrial                20000.             6700.           0.9571          8.726E-06            0.002493
    Coin-Op                   22000.             6000.           0.8571          6.998E-06            0.002199

Service Users
-------------
    Commercial Dry Clean   50000000.              2.80         0.000400          1.524E-12           1.089E-06
    Coin-Op Dry Clean      25000000.             10.00         0.001429          1.944E-11           6.942E-06
    Coin-Op Laundry        37000000.             38.00         0.005429          2.807E-10            0.000148

Urban Residents
---------------
      25 -  200 *           3700000.              2.52         0.000360          1.234E-12           6.525E-08
     200 -  500 *          20000000.            0.4320        6.171E-05          3.628E-14           1.036E-08
     500 - 1000 *          71000000.            0.1440        2.057E-05          4.031E-15           4.088E-09
                                                                                                 -------------
                                                                                      Total           0.0511

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -11.25
```

```
                              OPTION 1

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =        0.000203
Option cost (millions of dollars) =-11.30  Cost per cancer case (millions of dollars) =  1.00

     Type of                           Number in                                                       Expected Lifetime          Expected
     Person                                               Average Annual Exposure                          Incidence              Annual Cases
     ------                         U. S. Population  (micro gms/cubic m)      (mg/kg/day)         (probability/lifetime)    (number/year)
                                    ----------------  -------------------      -----------         ----------------------    -------------
Machine Operators
-----------------
    Commercial                           16000.              27000.                 3.86                 0.000782                 0.1787
    Industrial                             700.              30150.                 4.31                 0.000873               0.008729
    Coin-Up                              11000.               6000.               0.8571                 0.000174                 0.0273

Other Workers
-------------
    Commercial                           11000C.              6000.               0.8571                 0.000174                 0.2730
    Industrial                           20000.               6700.               0.9571                 0.000194                 0.0554
    Coin-Op                              22000.               6000.               0.8571                 0.000174                 0.0546

Service Users
-------------
    Commercial Dry Clean              50000000.                2.80             0.000400                8.110E-08                 0.0579
    Coin-Up Dry Clean                 25000000.               10.00             0.001429                2.896E-07                 0.1034
    Coin-Op Laundry                   37000000.               38.00             0.005429                1.101E-06                 0.5817

Urban Residents
---------------
      25 -  200 *                      3700000.                2.52             0.000360                7.299E-08               0.003858
     200 -  500 *                     20000000.              0.4320            6.171E-05                1.251E-08               0.003575
     500 - 1000 *                     71000000.              0.1440            2.057E-05                4.171E-09               0.004230
                                                                                                                            -------------
* Distance from dry cleaner in meters                                                                   Total                   1.35

Total cost of option and expected cancer (millions of dollars) =      -9.95
```

```
                    OPTION 1

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       8.013E-07
Option cost (millions of dollars) =-11.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime         Expected
     Type of                   Number in            Average Annual Exposure            Incidence           Annual Cases
     Person                U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                ----------------  -------------------      -----------   ---------------------- -------------

Machine Operators
-----------------
     Commercial                  16000.             27000.                3.86          1.192E-05            0.002725
     Industrial                    700.             30150.                4.31          1.484E-05            0.000148
     Coin-Op                     11000.              6000.              0.8571          5.887E-07           9.252E-05

Other Workers
-------------
     Commercial                 110000.              6000.              0.8571          5.887E-07            0.000925
     Industrial                  20000.              6700.              0.9571          7.341E-07            0.000210
     Coin-Op                     22000.              6000.              0.8571          5.887E-07            0.000185

Service Users
-------------
     Commercial Dry Clean     50000000.               2.80            0.000400          1.282E-13           9.158E-08
     Coin-Op Dry Clean        25000000.              10.00            0.001429          1.635E-12           5.841E-07
     Coin-Op Laundry          37000000.              38.00            0.005429          2.362E-11           1.248E-05

Urban Residents
---------------
     25 -  200 *               3700000.               2.52            0.000360          1.039E-13           5.489E-09
    200 -  500 *              20000000.             0.4320           6.171E-05          3.052E-15           8.720E-10
    500 - 1000 *              71000000.             0.1440           2.057E-05          3.391E-16           3.440E-10
                                                                                                         -------------
                                                                                   Total                 0.004299
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -11.30
```

```
                           OPTION 2

 Scaling:  SURFACE_AREA    Species:  MOUSE    Model:     LINEAR
 Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
 Option cost (millions of dollars) = -2.20  Cost per cancer case (millions of dollars) =  1.00

      Type of                    Number in            Average Annual Exposure         Expected Lifetime       Expected
      Person                  U. S. Population   (micro gms/cubic m)    (mg/kg/day)         Incidence          Annual Cases
      ------                  ----------------   -------------------    -----------  (probability/lifetime)  (number/year)
                                                                                     ----------------------  -------------
 Machine Operators
 -----------------
     Commercial                      16000.            45000.              6.43             0.2363              54.02
     Industrial                        700.            45000.              6.43             0.2363               2.36
     Coin-Op                         11000.             3300.            0.4714             0.0196               3.08
 Other Workers
 -------------
     Commercial                     110000.            10000.              1.43             0.0582              91.39
     Industrial                      20000.            10000.              1.43             0.0582              16.62
     Coin-Op                         22000.             3300.            0.4714             0.0196               6.15
 Service Users
 -------------
     Commercial Dry Clean         50000000.              5.00          0.000714          2.998E-05              21.42
     Coin-Op Dry Clean            25000000.              5.90          0.000843          3.535E-05              12.62
     Coin-Op Laundry              37000000.             20.90          0.002986           0.000125              66.19
 Urban Residents
 ---------------
      25 -  200 *                  3700000.              2.94          0.000420          1.764E-05             0.9326
     200 -  500 *                 20000000.            0.5040         7.200E-05          3.020E-06             0.8628
     500 - 1000 *                 71000000.            0.1680         2.400E-05          1.007E-06               1.02
                                                                                                          -------------
 * Distance from dry cleaner in meters                                                         Total             277.

 Total cost of option and expected cancer (millions of dollars) =    274.46
```

```
                    OPTION 2

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =       0.001675
Option cost (millions of dollars) = -2.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime         Expected
    Type of                     Number in            Average Annual Exposure        Incidence           Annual Cases
    Person                   U. S. Population   (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                   ----------------   -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                     16000.             45000.              6.43             0.0669              15.29
    Industrial                       700.             45000.              6.43             0.0669              0.6690
    Coin-Op                        11000.              3300.            0.4714           0.000372              0.0585

Other Workers
-------------
    Commercial                    110000.             10000.              1.43           0.003413               5.36
    Industrial                     20000.             10000.              1.43           0.003413             0.9753
    Coin-Op                        22000.              3300.            0.4714           0.000372             0.1170

Service Users
-------------
    Commercial Dry Clean        50000000.              5.00           0.000714          8.548E-10           0.000611
    Coin-Op Dry Clean           25000000.              5.90           0.000843          1.190E-09           0.000425
    Coin-Op Laundry             37000000.             20.90           0.002986          1.494E-08           0.007895

Urban Residents
---------------
     25 -  200 *                 3700000.              2.94           0.000420          2.956E-10          1.562E-05
    200 -  500 *                20000000.            0.5040          7.200E-05          8.686E-12          2.482E-06
    500 - 1000 *                71000000.            0.1680          2.400E-05          9.651E-13          9.789E-07
                                                                                                       -------------
                                                                                          Total              22.48
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     20.28
```

```
                        OPTION 2

Scaling:  SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) = -2.20  Cost per cancer case (millions of dollars) =  1.00

                                                                               Expected Lifetime       Expected
     Type of                     Number in          Average Annual Exposure        Incidence         Annual Cases
     Person                   U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                   ---------------   ------------------      -----------   ---------------------   ------------

Machine Operators
-----------------
     Commercial                     16000.            45000.               6.43            0.007593               1.74
     Industrial                       700.            45000.               6.43            0.007593             0.0759
     Coin-Op                        11000.             3300.             0.4714            0.000559             0.0878

Other Workers
-------------
     Commercial                    110000.            10000.               1.43            0.001692               2.66
     Industrial                     20000.            10000.               1.43            0.001692             0.4835
     Coin-Op                        22000.             3300.             0.4714            0.000559             0.1756

Service Users
-------------
     Commercial Dry Clean        50000000.              5.00           0.000714           8.469E-07             0.6049
     Coin-Op Dry Clean           25000000.              5.90           0.000843           9.993E-07             0.3569
     Coin-Op Laundry             37000000.             20.90           0.002986           3.540E-06               1.87

Urban Residents
---------------
     25 -  200 *                  3700000.              2.94           0.000420           4.980E-07             0.0263
    200 -  500 *                 20000000.            0.5040          7.200E-05           8.536E-08             0.0244
    500 - 1000 *                 71000000.            0.1680          2.400E-05           2.845E-08             0.0289
                                                                                                          ------------
                                                                                          Total               6.13
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      5.93
```

```
                                  OPTIUN 2

Scaling: SURFACE_AREA    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of    43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) = -2.20  Cost per cancer case (millions of dollars) =  1.00

     Type of                          Number in            Average Annual Exposure         Expected Lifetime       Expected
     Person                         U. S. Population  (micro gms/cubic m)    (mg/kg/day)       Incidence         Annual Cases
     ------                         ----------------  -------------------    -----------  (probability/lifetime)  (number/year)
                                                                                          ----------------------  ------------
Machine Operators
-----------------
     Commercial                         16000.              45000.               6.43         0.001132              0.2587
     Industrial                           700.              45000.               6.43         0.001132              0.0113
     Coin-Op                            11000.               3300.             0.4714        6.091E-06            0.000957

Other Workers
-------------
     Commercial                        110000.              10000.               1.43        5.591E-05              0.0879
     Industrial                         20000.              10000.               1.43        5.591E-05              0.0160
     Coin-Op                            22000.               3300.             0.4714        6.091E-06            0.001914

Service Users
-------------
     Commercial Dry Clean            50000000.                5.00           0.000714        1.398E-11           9.987E-06
     Coin-Op Dry Clean               25000000.                5.90           0.000843        1.947E-11           6.953E-06
     Coin-Op Laundry                 37000000.               20.90           0.002986        2.443E-10            0.000129

Urban Residents
---------------
       25 -  200 *                    3700000.                2.94           0.000420        4.834E-12           2.555E-07
      200 -  500 *                   20000000.              0.5040          7.200E-05        1.421E-13           4.059E-08
      500 - 1000 *                   71000000.              0.1680          2.400E-05        1.579E-14           1.601E-08
                                                                                                                 -------------
* Distance from dry cleaner in meters                                                             Total             0.3769

Total cost of option and expected cancer (millions of dollars) =      -1.82
```

```
                OPTION 2

Scaling:   BODY_WEIGHT    Species: MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) = -2.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime        Expected
    Type of                     Number in            Average Annual Exposure          Incidence          Annual Cases
    Person                   U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                   ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.             45000.                6.43            0.0201                4.60
    Industrial                     700.             45000.                6.43            0.0201              0.2012
    Coin-Op                      11000.              3300.              0.4714          0.001490              0.2341

Other Workers
-------------
    Commercial                  110000.             10000.                1.43          0.004507                7.08
    Industrial                   20000.             10000.                1.43          0.004507                1.29
    Coin-Op                      22000.              3300.              0.4714          0.001490              0.4682

Service Users
-------------
    Commercial Dry Clean      50000000.               5.00            0.000714         2.259E-06                1.61
    Coin-Op Dry Clean         25000000.               5.90            0.000843         2.665E-06              0.9519
    Coin-Op Laundry           37000000.              20.90            0.002986         9.441E-06                4.99

Urban Residents
---------------
     25 -  200 *               3700000.               2.94            0.000420         1.328E-06              0.0702
    200 -  500 *              20000000.             0.5040           7.200E-05         2.277E-07              0.0650
    500 - 1000 *              71000000.             0.1680           2.400E-05         7.589E-08              0.0770
                                                                                                         -------------
                                                                                       Total                   21.64
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     19.44
```

```
                              OPTION 2

Scaling:  BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) = -2.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime        Expected
     Type of                      Number in          Average Annual Exposure         Incidence          Annual Cases
     Person                    U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                    ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                        16000.            45000.              6.43          0.000394             0.0899
    Industrial                          700.            45000.              6.43          0.000394             0.003935
    Coin-Op                           11000.             3300.            0.4714          2.117E-06            0.000333

Other Workers
-------------
    Commercial                       110000.            10000.              1.43          1.943E-05            0.0305
    Industrial                        20000.            10000.              1.43          1.943E-05            0.005552
    Coin-Op                           22000.             3300.            0.4714          2.117E-06            0.000665

Service Users
-------------
    Commercial Dry Clean           50000000.              5.00          0.000714          4.859E-12            3.471E-06
    Coin-Op Dry Clean              25000000.              5.90          0.000843          6.766E-12            2.417E-06
    Coin-Op Laundry                37000000.             20.90          0.002986          8.491E-11            4.488E-05

Urban Residents
---------------
     25 -  200 *                    3700000.              2.94          0.000420          1.680E-12            8.881E-08
    200 -  500 *                   20000000.            0.5040         7.200E-05          4.937E-14            1.411E-08
    500 - 1000 *                   71000000.            0.1680         2.400E-05          5.486E-15            5.564E-09
                                                                                                           -------------
                                                                                               Total             0.1310
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -2.07
```

```
                             OPTION 2

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253,0 mg/kg/day which implies lambda =       0,000203
Option cost (millions of dollars) = -2,20  Cost per cancer case (millions of dollars) =  1,00

                                                                              Expected Lifetime       Expected
     Type of                    Number in           Average Annual Exposure        Incidence        Annual Cases
     Person                  U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                  ----------------  -------------------    -----------  ---------------------  ------------

Machine Operators
-----------------
    Commercial                     16000.            45000.              6,43          0,001302             0,2977
    Industrial                       700.            45000.              6,43          0,001302             0,0130
    Coin-Op                        11000.             3300.            0,4714         9,555E-05             0,0150

Other Workers
-------------
    Commercial                    110000.            10000.              1,43          0,000290             0,4550
    Industrial                     20000.            10000.              1,43          0,000290             0,0827
    Coin-Op                        22000.             3300.            0,4714         9,555E-05             0,0300

Service Users
-------------
    Commercial Dry Clean       50000000.              5,00          0,000714         1,448E-07             0,1034
    Coin-Op Dry Clean          25000000.              5,90          0,000843         1,709E-07             0,0610
    Coin-Op Laundry            37000000.             20,90          0,002986         6,053E-07             0,3200

Urban Residents
---------------
      25 -  200 *               3700000.              2,94          0,000420         8,515E-08           0,004501
     200 -  500 *              20000000.            0,5040         7,200E-05         1,460E-08           0,004171
     500 - 1000 *              71000000.            0,1680         2,400E-05         4,866E-09           0,004935
                                                                                                      -------------
                                                                                         Total              1,39
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -0,81
```

```
                        OPTION 2

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) = -2.20  Cost per cancer case (millions of dollars) =  1.00

    Type of                     Number in               Average Annual Exposure         Expected Lifetime       Expected
    Person                   U. S. Population  (micro gms/cubic m)    (mg/kg/day)          Incidence          Annual Cases
    ------                   ----------------  -------------------    -----------  (probability/lifetime)  (number/year)
                                                                                   ----------------------  -------------
Machine Operators
-----------------
     Commercial                   16000.             45000.               6.43          3.314E-05            0.007575
     Industrial                     700.             45000.               6.43          3.314E-05            0.000331
     Coin-Up                      11000.              3300.             0.4714          1.781E-07           2.794E-05

Other Workers
-------------
     Commercial                  110000.             10000.               1.43          1.635E-06            0.002570
     Industrial                   20000.             10000.               1.43          1.635E-06            0.000467
     Coin-Op                      22000.              3300.             0.4714          1.781E-07           5.597E-05

Service Users
-------------
     Commercial Dry Clean      50000000.               5.00           0.000714          4.088E-13           2.920E-07
     Coin-Up Dry Clean         25000000.               5.90           0.000843          5.693E-13           2.033E-07
     Coin-Op Laundry           37000000.              20.90           0.002986          7.144E-12           3.776E-06

Urban Residents
---------------
      25 -  200 *               3700000.               2.94           0.000420          1.414E-13           7.472E-09
     200 -  500 *              20000000.             0.5040          7.200E-05          4.154E-15           1.187E-09
     500 - 1000 *              71000000.             0.1680          2.400E-05          4.616E-16           4.682E-10
                                                                                                         -------------
* Distance from dry cleaner in meters                                                      Total             0.0110

Total cost of option and expected cancer (millions of dollars) =     -2.19
```

```
                        OPTION 3

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime        Expected
   Type of                  Number in            Average Annual Exposure                Incidence          Annual Cases
   Person                 U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                 ----------------  -------------------      -----------   ---------------------   -------------

Machine Operators
-----------------
    Commercial                  16000.            36450.                 5.21            0.1962               44.84
    Industrial                    700.            43200.                 6.17            0.2280                2.28
    Coin-Up                     11000.             6000.               0.8571            0.0353                5.55

Other Workers
-------------
    Commercial                 110000.             8100.                 1.16            0.0474               74.44
    Industrial                  20000.             9600.                 1.37            0.0559               15.97
    Coin-Op                     22000.             6000.               0.8571            0.0353               11.10

Service Users
-------------
    Commercial Dry Clean     50000000.             4.45              0.000636          2.664E-05              19.03
    Coin-Op Dry Clean        25000000.            10.00              0.001429          5.990E-05              21.39
    Coin-Op Laundry          37000000.            38.00              0.005429           0.000228              120.

Urban Residents
---------------
     25 -  200 *              3700000.             3.12              0.000445          1.866E-05              0.9861
    200 -  500 *             20000000.           0.5340             7.629E-05          3.199E-06              0.9141
    500 - 1000 *             71000000.           0.1780             2.543E-05          1.066E-06                1.08
                                                                                                          -------------
                                                                                         Total                 318.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    314.60
```

```
                     OPTION 3

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of    25.0 mg/kg/day which implies lambda =        0.001675
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                     Expected Lifetime         Expected
      Type of                        Number in           Average Annual Exposure          Incidence          Annual Cases
      Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
      ------                     ----------------  -------------------     -----------  ----------------------  ------------

Machine Operators
-----------------
     Commercial                        16000.             36450.               5.21              0.0444             10.15
     Industrial                          700.             43200.               6.17              0.0618             0.6162
     Coin-Op                           11000.              6000.             0.8571            0.001230             0.1933

Other Workers
-------------
     Commercial                       110000.              8100.               1.16            0.002241               3.52
     Industrial                        20000.              9600.               1.37            0.003146             0.8989
     Coin-Op                           22000.              6000.             0.8571            0.001230             0.3866

Service Users
-------------
     Commercial Dry Clean           50000000.              4.45            0.000636           6.771E-10           0.000484
     Coin-Op Dry Clean              25000000.             10.00            0.001429           3.419E-09           0.001221
     Coin-Op Laundry                37000000.             38.00            0.005429           4.937E-08             0.0261

Urban Residents
---------------
      25 -  200 *                    3700000.              3.12            0.000445           3.318E-10          1.754E-05
     200 -  500 *                   20000000.            0.5340           7.629E-05           9.750E-12          2.786E-06
     500 - 1000 *                   71000000.            0.1780           2.543E-05           1.083E-12          1.099E-06
                                                                                                             -------------
                                                                                            Total                 15.80
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     12.50
```

```
                     OPTION 3

Scaling: SURFACE_AREA     Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                       Expected Lifetime        Expected
     Type of                     Number in              Average Annual Exposure           Incidence           Annual Cases
     Person                   U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                   ----------------  -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                     16000.             36450.                5.21            0.006155               1.41
     Industrial                       700.             43200.                6.17            0.007290             0.0729
     Coin-Op                        11000.              6000.              0.8571            0.001016             0.1596

Other Workers
-------------
     Commercial                    110000.              8100.                1.16            0.001371               2.15
     Industrial                     20000.              9600.                1.37            0.001625             0.4642
     Coin-Op                        22000.              6000.              0.8571            0.001016             0.3192

Service Users
-------------
     Commercial Dry Clean        50000000.              4.45             0.000636           7.537E-07             0.5384
     Coin-Op Dry Clean           25000000.             10.00             0.001429           1.694E-06             0.6049
     Coin-Op Laundry             37000000.             38.00             0.005429           6.436E-06               3.40

Urban Residents
---------------
      25 -  200 *                 3700000.              3.12             0.000445           5.276E-07             0.0279
     200 -  500 *                20000000.            0.5340            7.629E-05           9.045E-08             0.0258
     500 - 1000 *                71000000.            0.1780            2.543E-05           3.015E-08             0.0306
                                                                                                             -------------
                                                                                                Total             9.21
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      5.91
```

```
                          OPTION 3

Scaling: SURFACE_AREA    Species:    RAT    Model: QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

   Type of                     Number in           Average Annual Exposure         Expected Lifetime        Expected
   Person                   U. S. Population  (micro gms/cubic m)     (mg/kg/day)       Incidence           Annual Cases
   ------                   ----------------  ------------------      -----------  (probability/lifetime) (number/year)
                                                                                    ---------------------- -------------
Machine Operators
-----------------
     Commercial                   16000.            36450.               5.21          0.000743              0.1698
     Industrial                     700.            43200.               6.17          0.001043              0.0104
     Coin-Op                      11000.             6000.             0.8571          2.015E-05           0.003166

Other Workers
-------------
     Commercial                  110000.             8100.               1.16          3.672E-05             0.0577
     Industrial                   20000.             9600.               1.37          5.156E-05             0.0147
     Coin-Op                      22000.             6000.             0.8571          2.015E-05           0.006332

Service Users
-------------
     Commercial Dry Clean      50000000.              4.45          0.000636          1.108E-11          7.911E-06
     Coin-Op Dry Clean         25000000.             10.00          0.001429          5.593E-11          1.997E-05
     Coin-Op Laundry           37000000.             38.00          0.005429          8.076E-10           0.000427

Urban Residents
---------------
      25 -  200 *               3700000.              3.12          0.000445          5.427E-12          2.868E-07
     200 -  500 *              20000000.            0.5340         7.629E-05          1.595E-13          4.557E-08
     500 - 1000 *              71000000.            0.1780         2.543E-05          1.772E-14          1.797E-08
                                                                                                       -------------
* Distance from dry cleaner in meters                                                  Total             0.2626

Total cost of option and expected cancer (millions of dollars) =     -3.04
```

```
                    OPTION 3

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =        0.003162
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
    Type of                    Number in           Average Annual Exposure            Incidence          Annual Cases
    Person                  U. S. Population   (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
    ------                  ----------------   -------------------    -----------  ---------------------   ------------

Machine Operators
-----------------
     Commercial                  16000.              36450.              5.21             0.0163               3.73
     Industrial                    700.              43200.              6.17             0.0193             0.1933
     Coin-Op                     11000.               6000.            0.8571           0.002707             0.4253

Other Workers
-------------
     Commercial                 110000.               8100.              1.16           0.003652               5.74
     Industrial                  20000.               9600.              1.37           0.004327               1.24
     Coin-Op                     22000.               6000.            0.8571           0.002707             0.8507

Service Users
-------------
     Commercial Dry Clean     50000000.               4.45           0.000636          2.010E-06               1.84
     Coin-Op Dry Clean        25000000.              10.00           0.001429          4.517E-06               1.61
     Coin-Op Laundry          37000000.              38.00           0.005429          1.717E-05               9.07

Urban Residents
---------------
      25 -  200 *              3700000.               3.12           0.000445          1.407E-06             0.0744
     200 -  500 *             20000000.             0.5340          7.629E-05          2.412E-07             0.0689
     500 - 1000 *             71000000.             0.1780          2.543E-05          8.041E-08             0.0816
                                                                                                       -------------
                                                                                     Total                 24.53
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     21.23
```

```
                              OPTIUN 3

Scaling:  BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime        Expected
   Type of                    Number in             Average Annual Exposure           Incidence          Annual Cases
   Person                  U. S. Population   (micro gms/cubic m)       (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                  ----------------   -------------------       -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                  16000.             36450.                 5.21            0.000258            0.0590
     Industrial                    700.             43200.                 6.17            0.000363            0.003627
     Coin-Up                     11000.              6000.                 0.8571          6.998E-06           0.001100

Other Workers
-------------
     Commercial                 110000.              8100.                 1.16            1.276E-05           0.0200
     Industrial                  20000.              9600.                 1.37            1.794E-05           0.005126
     Coin-Op                     22000.              6000.                 0.8571          6.998E-06           0.002199

Service Users
-------------
     Commercial Dry Clean     50000000.                 4.45               0.000636        3.849E-12           2.749E-06
     Coin-Op Dry Clean        25000000.                10.00               0.001429        1.944E-11           6.942E-06
     Coin-Op Laundry          37000000.                38.00               0.005429        2.807E-10           0.000148

Urban Residents
---------------
      25 -  200 *              3700000.                 3.12               0.000445        1.886E-12           9.969E-08
     200 -  500 *             20000000.                 0.5340             7.629E-05       5.543E-14           1.584E-08
     500 - 1000 *             71000000.                 0.1780             2.543E-05       6.159E-15           6.247E-09
                                                                                                             -------------
                                                                                             Total             0.0913
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -3.21
```

```
                     OPTION 3

Scaling:  BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime      Expected
   Type of                        Number in           Average Annual Exposure          Incidence         Annual Cases
   Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                     ----------------  -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
     Commercial                     16000.            36450.                5.21          0.001055             0.2412
     Industrial                       700.            43200.                6.17          0.001250             0.0125
     Coin-Op                        11000.             6000.              0.8571          0.000174             0.0273

Other Workers
-------------
     Commercial                    110000.             8100.                1.16          0.000235             0.3686
     Industrial                     20000.             9600.                1.37          0.000278             0.0794
     Coin-Op                        22000.             6000.              0.8571          0.000174             0.0546

Service Users
-------------
     Commercial Dry Clean        50000000.             4.45             0.000636          1.289E-07            0.0921
     Coin-Op Dry Clean           25000000.            10.00             0.001429          2.896E-07            0.1034
     Coin-Op Laundry             37000000.            38.00             0.005429          1.101E-06            0.5617

Urban Residents
---------------
      25 -  200 *                 3700000.             3.12             0.000445          9.022E-08            0.004769
     200 -  500 *                20000000.           0.5340            7.629E-05          1.547E-08            0.004419
     500 - 1000 *                71000000.           0.1780            2.543E-05          5.155E-09            0.005229
                                                                                                           -------------
                                                                                       Total                 1.58
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -1.72
```

```
                                 OPTION 3

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) = -3.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime       Expected
     Type of                       Number in           Average Annual Exposure          Incidence          Annual Cases
     Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                     ----------------  -------------------     -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                       16000.            36450.                5.21           2.176E-05            0.004973
     Industrial                         700.            43200.                6.17           3.052E-05            0.000305
     Coin-Op                          11000.             6000.              0.8571           5.887E-07           9.252E-05

Other Workers
-------------
     Commercial                      110000.             8100.                1.16           1.073E-06            0.001686
     Industrial                       20000.             9600.                1.37           1.507E-06            0.000431
     Coin-Op                          22000.             6000.              0.8571           5.887E-07            0.000165

Service Users
-------------
     Commercial Dry Clean          50000000.             4.45             0.000636           3.238E-13           2.313E-07
     Coin-Op Dry Clean             25000000.            10.00             0.001429           1.635E-12           5.841E-07
     Coin-Op Laundry               37000000.            38.00             0.005429           2.362E-11           1.248E-05

Urban Residents
---------------
      25 -  200 *                   3700000.             3.12             0.000445           1.587E-13           8.388E-09
     200 -  500 *                  20000000.           0.5340            7.629E-05           4.663E-15           1.332E-09
     500 - 1000 *                  71000000.           0.1760            2.543E-05           5.182E-16           5.256E-10
                                                                                                             -------------
                                                                                              Total           0.007686
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -3.29
```

```
                     OPTION 4

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =          0.0419
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime        Expected
     Type of                    Number in           Average Annual Exposure           Incidence          Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.             45000.               6.43             0.2363              54.02
    Industrial                     700.             45000.               6.43             0.2363               2.36
    Coin-Op                      11000.              4020.             0.5743             0.0238               3.74

Other Workers
-------------
    Commercial                  110000.             10000.               1.43             0.0582              91.39
    Industrial                   20000.             10000.               1.43             0.0582              16.62
    Coin-Op                      22000.              4020.             0.5743             0.0238               7.48

Service Users
-------------
    Commercial Dry Clean      50000000.               5.00           0.000714          2.998E-05              21.42
    Coin-Op Dry Clean         25000000.               7.40           0.001057          4.435E-05              15.84
    Coin-Op Laundry           37000000.              25.46           0.003637           0.000153              80.62

Urban Residents
---------------
     25 -  200 *               3700000.               3.26           0.000465          1.949E-05               1.03
    200 -  500 *              20000000.             0.5580          7.971E-05          3.343E-06             0.9552
    500 - 1000 *              71000000.             0.1860          2.657E-05          1.114E-06               1.13
                                                                                                       -------------
                                                                                          Total                297.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    296.89
```

```
                                OPTION 4

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =       0.001675
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime          Expected
     Type of                   Number in              Average Annual Exposure         Incidence          Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)        (mg/kg/day)    (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------        -----------    ----------------------  -------------

Machine Operators
-----------------
     Commercial                   16000.               45000.               6.43               0.0669            15.29
     Industrial                     700.               45000.               6.43               0.0669            0.6690
     Coin-Op                      11000.                4020.             0.5743             0.000552            0.0868

Other Workers
-------------
     Commercial                  110000.               10000.               1.43             0.003413             5.36
     Industrial                   20000.               10000.               1.43             0.003413            0.9753
     Coin-Op                      22000.                4020.             0.5743             0.000552            0.1736

Service Users
-------------
     Commercial Dry Clean     50000000.                 5.00           0.000714            8.548E-10          0.000611
     Coin-Up Dry Clean        25000000.                 7.40           0.001057            1.872E-09          0.000669
     Coin-Op Laundry          37000000.                25.46           0.003637            2.216E-08            0.0117

Urban Residents
---------------
       25 -  200 *             3700000.                 3.26           0.000465            3.623E-10         1.915E-05
      200 -  500 *            20000000.               0.5580          7.971E-05            1.065E-11         3.042E-06
      500 - 1000 *            71000000.               0.1860          2.657E-05            1.183E-12         1.200E-06
                                                                                                          -------------
                                                                                             Total             22.57
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      22.87
```

```
                     OPTION 4

Scaling:  SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =        0.001186
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime          Expected
      Type of                     Number in              Average Annual Exposure            Incidence            Annual Cases
      Person                   U. S. Population  (micro gms/cubic m)      (mg/kg/day)     (probability/lifetime)  (number/year)
      ------                   ----------------  -------------------      -----------     ----------------------  -------------

Machine Operators
-----------------
     Commercial                     16000.             45000.                 6.43           0.007593                  1.74
     Industrial                       700.             45000.                 6.43           0.007593                0.0759
     Coin-Op                        11000.              4020.               0.5743           0.000681                0.1070

Other Workers
-------------
     Commercial                    110000.             10000.                 1.43           0.001692                  2.66
     Industrial                     20000.             10000.                 1.43           0.001692                0.4835
     Coin-Op                        22000.              4020.               0.5743           0.000681                0.2139

Service Users
-------------
     Commercial Dry Clean        50000000.               5.00             0.000714           8.469E-07               0.6049
     Coin-Op Dry Clean           25000000.               7.40             0.001057           1.253E-06               0.4476
     Coin-Op Laundry             37000000.              25.46             0.003637           4.312E-06                 2.28

Urban Residents
---------------
      25 -  200 *                 3700000.               3.26             0.000465           5.513E-07               0.0291
     200 -  500 *                20000000.             0.5580            7.971E-05           9.451E-08               0.0270
     500 - 1000 *                71000000.             0.1850            2.657E-05           3.150E-08               0.0320
                                                                                                                -------------
* Distance from dry cleaner in meters                                                        Total                     8.70

Total cost of option and expected cancer (millions of dollars) =      9.00
```

```
                         OPTION 4

Scaling: SURFACE_AREA    Species:    RAT    Model: QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                       Expected Lifetime       Expected
  Type of                        Number in            Average Annual Exposure              Incidence          Annual Cases
  Person                      U. S. Population   (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
  ------                      ----------------   -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                      16000.              45000.                6.43           0.001132             0.2587
    Industrial                        700.              45000.                6.43           0.001132             0.0113
    Coin-Op                         11000.               4020.              0.5743           9.038E-06            0.001420

Other Workers
-------------
    Commercial                     110000.              10000.                1.43           5.591E-05            0.0879
    Industrial                      20000.              10000.                1.43           5.591E-05            0.0160
    Coin-Op                         22000.               4020.              0.5743           9.038E-06            0.002841

Service Users
-------------
    Commercial Dry Clean         50000000.               5.00             0.000714           1.398E-11         9.987E-06
    Coin-Op Dry Clean            25000000.               7.40             0.001057           3.063E-11         1.094E-05
    Coin-Op Laundry              37000000.              25.46             0.003637           3.625E-10          0.000192

Urban Residents
---------------
     25 -  200 *                  3700000.               3.26             0.000465           5.926E-12         3.132E-07
    200 -  500 *                 20000000.             0.5580            7.971E-05           1.741E-13         4.975E-08
    500 - 1000 *                 71000000.             0.1860            2.657E-05           1.935E-14         1.963E-08
                                                                                                              -------------
                                                                                              Total             0.3783
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      0.68
```

```
                    OPTION 4

Scaling:  BODY_WEIGHT    Species:  MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime       Expected
     Type of                          Number in          Average Annual Exposure        Incidence         Annual Cases
     Person                       U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                       ----------------  -------------------     -----------  ---------------------  -------------

Machine Operators
-----------------
    Commercial                         16000.             45000.              6.43             0.0201              4.60
    Industrial                           700.             45000.              6.43             0.0201              0.2012
    Coin-Op                            11000.              4020.            0.5743           0.001614              0.2651

Other Workers
-------------
    Commercial                        110000.             10000.              1.43           0.004507              7.08
    Industrial                         20000.             10000.              1.43           0.004507              1.29
    Coin-Op                            22000.              4020.            0.5743           0.001614              0.5702

Service Users
-------------
    Commercial Dry Clean            50000000.              5.00           0.000714          2.259E-06              1.61
    Coin-Op Dry Clean               25000000.              7.40           0.001057          3.343E-06              1.19
    Coin-Op Laundry                 37000000.             25.46           0.003637          1.150E-05              6.08

Urban Residents
---------------
     25 -  200 *                     3700000.              3.26           0.000465          1.470E-06              0.0777
    200 -  500 *                    20000000.            0.5580          7.971E-05          2.521E-07              0.0720
    500 - 1000 *                    71000000.            0.1860          2.657E-05          8.402E-08              0.0852
                                                                                                            -------------
                                                                                               Total             23.15
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     23.45
```

```
                    OPTION 4

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime        Expected
     Type of                       Number in          Average Annual Exposure       Incidence          Annual Cases
     Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                     ---------------   ------------------     -----------   ---------------------  ------------

Machine Operators
-----------------
    Commercial                      16000.            45000.               6.43          0.000394            0.0899
    Industrial                        700.            45000.               6.43          0.000394            0.003935
    Coin-Op                         11000.             4020.             0.5743         3.141E-06            0.000494

Other Workers
-------------
    Commercial                     110000.            10000.               1.43         1.943E-05            0.0305
    Industrial                      20000.            10000.               1.43         1.943E-05            0.005552
    Coin-Op                         22000.             4020.             0.5743         3.141E-06            0.000987

Service Users
-------------
    Commercial Dry Clean         50000000.              5.00           0.000714         4.859E-12           3.471E-06
    Coin-Op Dry Clean            25000000.              7.40           0.001057         1.064E-11           3.801E-06
    Coin-Op Laundry              37000000.             25.46           0.003637         1.260E-10           6.660E-05

Urban Residents
---------------
     25 -  200 *                  3700000.              3.26           0.000465         2.059E-12           1.089E-07
    200 -  500 *                 20000000.            0.5580          7.971E-05         6.052E-14           1.729E-08
    500 - 1000 *                 71000000.            0.1860          2.657E-05         6.725E-15           6.621E-09
                                                                                                          -------------
                                                                                           Total            0.1315
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      0.43
```

```
                    OPTION 4

Scaling:   BODY_WEIGHT    Species:   RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      0.000203
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                               Expected Lifetime        Expected
    Type of                   Number in          Average Annual Exposure           Incidence          Annual Cases
    Person                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                 ----------------  -------------------    -----------   ---------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.             45000.             6.43           0.001302             0.2977
    Industrial                     700.             45000.             6.43           0.001302             0.0130
    Coin-Up                      11000.              4020.           0.5743           0.000116             0.0183

Other Workers
-------------
    Commercial                  110000.             10000.             1.43           0.000290             0.4550
    Industrial                   20000.             10000.             1.43           0.000290             0.0827
    Coin-Op                      22000.              4020.           0.5743           0.000116             0.0366

Service Users
-------------
    Commercial Dry Clean      50000000.              5.00          0.000714          1.448E-07             0.1034
    Coin-Op Dry Clean         25000000.              7.40          0.001057          2.143E-07             0.0765
    Coin-Up Laundry           37000000.             25.46          0.003637          7.374E-07             0.3898

Urban Residents
---------------
     25 -  200 *               3700000.              3.26          0.000465          9.427E-08           0.004983
    200 -  500 *              20000000.            0.5580         7.971E-05          1.616E-08           0.004618
    500 - 1000 *              71000000.            0.1860         2.657E-05          5.387E-09           0.005464
                                                                                                     -------------
* Distance from dry cleaner in meters                                               Total               1.49

Total cost of option and expected cancer (millions of dollars) =      1.79
```

```
                    OPTION 4

Scaling:  BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) =  0.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime        Expected
     Type of                     Number in              Average Annual Exposure      Incidence          Annual Cases
     Person                   U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                   ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                     16000.              45000.              6.43           3.314E-05          0.007575
     Industrial                       700.              45000.              6.43           3.314E-05          0.000331
     Coin-Op                        11000.               4020.            0.5743           2.643E-07         4.153E-05

Other Workers
-------------
     Commercial                    110000.              10000.              1.43           1.635E-06          0.002570
     Industrial                     20000.              10000.              1.43           1.635E-06          0.000467
     Coin-Op                        22000.               4020.            0.5743           2.643E-07         6.306E-05

Service Users
-------------
     Commercial Dry Clean        50000000.               5.00           0.000714           4.088E-13         2.920E-07
     Coin-Op Dry Clean           25000000.               7.40           0.001057           8.955E-13         3.198E-07
     Coin-Op Laundry             37000000.              25.46           0.003637           1.060E-11         5.603E-06

Urban Residents
---------------
      25 -  200 *                 3700000.               3.26           0.000465           1.733E-13         9.159E-09
     200 -  500 *                20000000.             0.5580          7.971E-05           5.092E-15         1.455E-09
     500 - 1000 *                71000000.             0.1860          2.657E-05           5.658E-16         5.739E-10
                                                                                                        -------------
                                                                                         Total             0.0111
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      0.31
```

OPTION 5

```
Scaling: SURFACE_AREA   Species: MOUSE   Model:    LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =         0.0419
Option cost (millions of dollars) =  8.70  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime        Expected
   Type of                   Number in                Average Annual Exposure        Incidence          Annual Cases
   Person                 U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                 ----------------  -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                    16000.            29700.               4.24             0.1630              37.26
    Industrial                      700.            45000.               6.43             0.2363               2.36
    Coin-Op                       11000.             6000.             0.8571             0.0353               5.55

Other Workers
-------------
    Commercial                   110000.            10000.               1.43             0.0582              91.39
    Industrial                    20000.            10000.               1.43             0.0582              16.62
    Coin-Op                       22000.             6000.             0.8571             0.0353              11.10

Service Users
-------------
    Commercial Dry Clean       50000000.              5.00           0.000714          2.998E-05              21.42
    Coin-Op Dry Clean          25000000.             10.00           0.001429          5.990E-05              21.39
    Coin-Op Laundry            37000000.             38.00           0.005429           0.000228              120.

Urban Residents
---------------
    .25 -  200 *                3700000.              3.50           0.000500          2.098E-05               1.11
    200 -  500 *               20000000.            0.6000          8.571E-05          3.595E-06               1.03
    500 - 1000 *               71000000.            0.2000          2.857E-05          1.198E-06               1.22
                                                                                                      ------------
                                                                                        Total              331.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    339.45
```

```
                    OPTIUN 5

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of   25,0 mg/kg/day which implies lambda =       0,001675
Option cost (millions of dollars) =  8,70  Cost per cancer case (millions of dollars) =  1,00

                                                                                Expected Lifetime       Expected
    Type of                  Number in             Average Annual Exposure          Incidence          Annual Cases
    Person                U, S, Population   (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
    ------                ---------------- ---------------------   -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                  16000,             29700,               4,24              0,0297             6,79
    Industrial                    700,             45000,               6,43              0,0669            0,6690
    Coin-Up                     11000,              6000,             0,8571            0,001230            0,1933

Other Workers
-------------
    Commercial                 110000,             10000,               1,43            0,003413             5,36
    Industrial                  20000,             10000,               1,43            0,003413            0,9753
    Coin-Op                     22000,              6000,             0,8571            0,001230            0,3866

Service Users
-------------
    Commercial Dry Clean     50000000,              5,00            0,000714           8,548E-10          0,000611
    Coin-Op Dry Clean        25000000,             10,00            0,001429           3,419E-09          0,001221
    Coin-Op Laundry          37000000,             38,00            0,005429           4,937E-08            0,0261

Urban Residents
---------------
    25 -  200 *               3700000,              3,50            0,000500           4,189E-10         2,214E-05
   200 -  500 *              20000000,            0,6000           8,571E-05           1,231E-11         3,517E-06
   500 - 1000 *              71000000,            0,2000           2,857E-05           1,368E-12         1,387E-06
                                                                                                       -------------
                                                                                          Total            14,41
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     23,11
```

```
                    OPTION 5

Scaling:  SURFACE_AREA    Species:    RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) =  8.70  Cost per cancer case (millions of dollars) =  1.00

                                                                                     Expected Lifetime         Expected
     Type of                          Number in            Average Annual Exposure       Incidence            Annual Cases
     Person                       U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                       ----------------  -------------------     -----------  ----------------------  ------------

Machine Operators
-----------------
    Commercial                        16000.             29700.                4.24           0.005018                1.15
    Industrial                          700.             45000.                6.43           0.007593                0.0759
    Coin-Op                           11000.              6000.              0.8571           0.001016                0.1596

Other Workers
-------------
    Commercial                       110000.             10000.                1.43           0.001692                2.66
    Industrial                        20000.             10000.                1.43           0.001692                0.4835
    Coin-Op                           22000.              6000.              0.8571           0.001016                0.3192

Service Users
-------------
    Commercial Dry Clean           50000000.               5.00            0.000714           8.469E-07               0.6049
    Coin-Op Dry Clean              25000000.              10.00            0.001429           1.694E-06               0.6049
    Coin-Op Laundry                37000000.              38.00            0.005429           6.436E-06               3.40

Urban Residents
---------------
     25 -  200 *                    3700000.               3.50            0.000500           5.928E-07               0.0313
    200 -  500 *                   20000000.             0.6000           8.571E-05           1.016E-07               0.0290
    500 - 1000 *                   71000000.             0.2000           2.857E-05           3.387E-08               0.0344
                                                                                                                -------------
                                                                                               Total                  9.55
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     18.25
```

```
                              OPTION 5

Scaling: SURFACE_AREA    Species:    RAT    Model: QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =  8.70  Cost per cancer case (millions of dollars) =  1.00

                                                                                     Expected Lifetime        Expected
    Type of                   Number in           Average Annual Exposure                Incidence          Annual Cases
    Person                 U. S. Population  (micro gms/cubic m)       (mg/kg/day)  (probability/lifetime)  (number/year)
    ------                 ---------------- -------------------       -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                    16000.              29700.                4.24            0.000493            0.1127
    Industrial                      700.              45000.                6.43            0.001132            0.0113
    Coin-Op                       11000.               6000.              0.8571           2.015E-05          0.003166

Other Workers
-------------
    Commercial                   110000.              10000.                1.43           5.591E-05            0.0879
    Industrial                    20000.              10000.                1.43           5.591E-05            0.0160
    Coin-Op                       22000.               6000.              0.8571           2.015E-05          0.006332

Service Users
-------------
    Commercial Dry Clean      50000000.                5.00            0.000714           1.398E-11         9.987E-06
    Coin-Op Dry Clean         25000000.               10.00            0.001429           5.593E-11         1.997E-05
    Coin-Op Laundry           37000000.               38.00            0.005429           8.076E-10          0.000427

Urban Residents
---------------
      25 -  200 *              3700000.                3.50            0.000500           6.851E-12         3.621E-07
     200 -  500 *             20000000.              0.6000           8.571E-05           2.013E-13         5.753E-08
     500 - 1000 *             71000000.              0.2000           2.857E-05           2.237E-14         2.269E-08
                                                                                                          -------------
                                                                                            Total             0.2376
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      8.94
```

```
                  OPTION 5

Scaling:   BODY_WEIGHT    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) =  6.70  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime       Expected
    Type of                  Number in            Average Annual Exposure         Incidence         Annual Cases
    Person                U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                ----------------  -------------------     -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                  16000.            29700.               4.24            0.0133              3.05
    Industrial                    700.            45000.               6.43            0.0201              0.2012
    Coin-Op                     11000.             6000.             0.8571          0.002707              0.4253

Other workers
-------------
    Commercial                 110000.            10000.               1.43          0.004507              7.08
    Industrial                  20000.            10000.               1.43          0.004507              1.29
    Coin-Op                     22000.             6000.             0.8571          0.002707              0.8507

Service Users
-------------
    Commercial Dry Clean     50000000.              5.00           0.000714         2.259E-06              1.61
    Coin-Op Dry Clean        25000000.             10.00           0.001429         4.517E-06              1.61
    Coin-Op Laundry          37000000.             38.00           0.005429         1.717E-05              9.07

Urban Residents
---------------
     25 -  200 *              3700000.              3.50           0.000500         1.581E-06              0.0836
    200 -  500 *             20000000.            0.6000          8.571E-05         2.710E-07              0.0774
    500 - 1000 *             71000000.            0.2000          2.857E-05         9.035E-08              0.0916
                                                                                                    -------------
                                                                                        Total              25.45
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      34.15
```

```
                     OPTION 5

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) =  8.70  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime        Expected
    Type of                      Number in            Average Annual Exposure        Incidence          Annual Cases
    Person                   U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
    ------                   ----------------  -------------------    -----------  ---------------------  ------------

Machine Operators
-----------------
    Commercial                     16000.            29700.               4.24          0.000171              0.0392
    Industrial                       700.            45000.               6.43          0.000394            0.003935
    Coin-Op                        11000.             6000.             0.8571         6.998E-06            0.001100

Other Workers
-------------
    Commercial                    110000.            10000.               1.43         1.943E-05              0.0305
    Industrial                     20000.            10000.               1.43         1.943E-05            0.005552
    Coin-Op                        22000.             6000.             0.8571         6.998E-06            0.002199

Service Users
-------------
    Commercial Dry Clean        50000000.              5.00           0.000714         4.859E-12           3.471E-06
    Coin-Op Dry Clean           25000000.             10.00           0.001429         1.944E-11           6.942E-06
    Coin-Op Laundry             37000000.             38.00           0.005429         2.807E-10            0.000148

Urban Residents
---------------
     25 -  200 *                 3700000.              3.50           0.000500         2.381E-12           1.259E-07
    200 -  500 *                20000000.            0.6000          8.571E-05         6.996E-14           1.999E-08
    500 - 1000 *                71000000.            0.2000          2.857E-05         7.775E-15           7.886E-09
                                                                                                      ------------
                                                                                          Total             0.0827
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =       8.78
```

```
                           OPTION 5

Scaling:   BODY_WEIGHT    Species:    RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =        0.000203
Option cost (millions of dollars) =  8.70  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime      Expected
    Type of                        Number in          Average Annual Exposure        Incidence         Annual Cases
    Person                      U. S. Population  (micro gms/cubic m)    (mg/kg/day)    (probability/lifetime)  (number/year)
    ------                      ----------------  -------------------    -----------    ----------------------  -------------

Machine Operators
-----------------
    Commercial                        16000.           29700.              4.24           0.000860             0.1965
    Industrial                          700.           45000.              6.43           0.001302             0.0130
    Coin-Op                           11000.            6000.            0.8571           0.000174             0.0273

Other Workers
-------------
    Commercial                       110000.           10000.              1.43           0.000290             0.4550
    Industrial                        20000.           10000.              1.43           0.000290             0.0827
    Coin-Op                           22000.            6000.            0.8571           0.000174             0.0546

Service Users
-------------
    Commercial Dry Clean          50000000.             5.00          0.000714          1.448E-07             0.1034
    Coin-Op Dry Clean             25000000.            10.00          0.001429          2.896E-07             0.1034
    Coin-Op Laundry               37000000.            38.00          0.005429          1.101E-06             0.5817

Urban Residents
---------------
     25 -  200 *                   3700000.             3.50          0.000500          1.014E-07             0.005358
    200 -  500 *                  20000000.           0.6000         8.571E-05          1.738E-08             0.004965
    500 - 1000 *                  71000000.           0.2000         2.857E-05          5.793E-09             0.005675
                                                                                                          -------------
                                                                                           Total               1.63
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     10.33
```

```
                        OPTION 5

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) =  8.70  Cost per cancer case (millions of dollars) =  1.00
                                                                                   Expected Lifetime          Expected
                                 Number in              Average Annual Exposure        Incidence           Annual Cases
     Type of                  U. S. Population   (micro gms/cubic m)   (mg/kg/day)  (probability/lifetime)  (number/year)
     Person                   ----------------   -------------------   -----------  ----------------------  ------------
     ------

Machine Operators
-----------------
    Commercial                     16000.              29700.              4.24          1.442E-05          0.003297
    Industrial                       700.              45000.              6.43          3.314E-05          0.000331
    Coin-Op                        11000.               6000.            0.8571          5.887E-07          9.252E-05

Other Workers
-------------
    Commercial                    110000.              10000.              1.43          1.635E-06          0.002570
    Industrial                     20000.              10000.              1.43          1.635E-06          0.000467
    Coin-Op                        22000.               6000.            0.8571          5.887E-07          0.000185

Service Users
-------------
    Commercial Dry Clean        50000000.                5.00          0.000714          4.088E-13          2.920E-07
    Coin-Op Dry Clean           25000000.               10.00          0.001429          1.635E-12          5.841E-07
    Coin-Op Laundry             37000000.               38.00          0.005429          2.362E-11          1.248E-05

Urban Residents
---------------
     25 -  200 *                 3700000.                3.50          0.000500          2.003E-13          1.059E-08
    200 -  500 *                20000000.              0.6000         8.571E-05          5.887E-15          1.682E-09
    500 - 1000 *                71000000.              0.2000         2.857E-05          6.542E-16          6.635E-10
                                                                                                         -------------
                                                                                         Total              0.006956

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      8.71
```

```
                    OPTION 6

Scaling:  SURFACE_AREA    Species:  MOUSE     Model:      LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                                        Expected Lifetime         Expected
    Type of                     Number in              Average Annual Exposure              Incidence           Annual Cases
    Person                  U. S. Population   (micro gms/cubic m)      (mg/kg/day)    (probability/lifetime)   (number/year)
    ------                  ----------------   -------------------      -----------    ----------------------   -------------

Machine Operators
-----------------
     Commercial                   16000.             45000.                 6.43              0.2363                 54.02
     Industrial                     700.             45000.                 6.43              0.2363                  2.36
     Coin-Op                      11000.              6000.               0.8571              0.0353                  5.55

Other Workers
-------------
     Commercial                  110000.             10000.                 1.43              0.0582                 91.39
     Industrial                   20000.             10000.                 1.43              0.0582                 16.62
     Coin-Op                      22000.              6000.               0.8571              0.0353                 11.10

Service Users
-------------
     Commercial Dry Clean      50000000.               5.00             0.000714           2.998E-05                 21.42
     Coin-Op Dry Clean         25000000.              10.00             0.001429           5.990E-05                 21.39
     Coin-Op Laundry           37000000.               3.80             0.000543           2.277E-05                 12.04

Urban Residents
---------------
     25 -  200 *                3700000.               3.50             0.000500           2.098E-05                  1.11
    200 -  500 *               20000000.             0.6000            8.571E-05           3.595E-06                  1.03
    500 - 1000 *               71000000.             0.2000            2.857E-05           1.198E-06                  1.22
                                                                                                                -------------
                                                                                               Total                  239.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    244.12
```

```
                        OPTION 6

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =      0.001675
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime      Expected
    Type of                   Number in          Average Annual Exposure          Incidence        Annual Cases
    Person                U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime) (number/year)
    ------                ----------------  -------------------     -----------  ---------------------- ------------

Machine Operators
-----------------
     Commercial                 16000.            45000.               6.43          0.0669             15.29
     Industrial                   700.            45000.               6.43          0.0669             0.6690
     Coin-Op                    11000.             6000.             0.8571        0.001230             0.1933

Other Workers
-------------
     Commercial                110000.            10000.               1.43        0.003413               5.36
     Industrial                 20000.            10000.               1.43        0.003413             0.9753
     Coin-Op                    22000.             6000.             0.8571        0.001230             0.3866

Service Users
-------------
     Commercial Dry Clean    50000000.              5.00           0.000714       8.548E-10           0.000611
     Coin-Op Dry Clean       25000000.             10.00           0.001429       3.419E-09           0.001221
     Coin-Op Laundry         37000000.              3.80           0.000543       4.937E-10           0.000261

Urban Residents
---------------
      25 -  200 *             3700000.              3.50           0.000500       4.189E-10          2.214E-05
     200 -  500 *            20000000.            0.6000          8.571E-05       1.231E-11          3.517E-06
     500 - 1000 *            71000000.            0.2000          2.857E-05       1.368E-12          1.387E-06
                                                                                                 -------------
                                                                                     Total           22.88

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     27.78
```

```
                         OPTION 6

Scaling:  SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                               Expected Lifetime       Expected
     Type of                     Number in            Average Annual Exposure       Incidence          Annual Cases
     Person                  U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                  ----------------  --------------------    -----------   ---------------------   -------------

Machine Operators
-----------------
    Commercial                    16000.             45000.               6.43          0.007593                1.74
    Industrial                      700.             45000.               6.43          0.007593              0.0759
    Coin-Op                       11000.              6000.             0.8571          0.001016              0.1596

Other Workers
-------------
    Commercial                   110000.             10000.               1.43          0.001692                2.66
    Industrial                    20000.             10000.               1.43          0.001692              0.4835
    Coin-Op                       22000.              6000.             0.8571          0.001016              0.3192

Service Users
-------------
    Commercial Dry Clean       50000000.               5.00           0.000714          8.469E-07             0.6049
    Coin-Op Dry Clean          25000000.              10.00           0.001429          1.694E-06             0.6049
    Coin-Op Laundry            37000000.               3.80           0.000543          6.436E-07             0.3402

Urban Residents
---------------
      25 -  200 *               3700000.               3.50           0.000500          5.928E-07             0.0313
     200 -  500 *              20000000.             0.6000          8.571E-05          1.016E-07             0.0290
     500 - 1000 *              71000000.             0.2000          2.857E-05          3.387E-08             0.0344
                                                                                                          -------------
                                                                                         Total                  7.06
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     11.98
```

```
                              OPTION 6

Scaling:  SURFACE_AREA    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of    43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                                         Expected Lifetime       Expected
    Type of                        Number in            Average Annual Exposure              Incidence           Annual Cases
    Person                     U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                     ----------------  -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                       16000.             45000.                6.43             0.001132           0.2587
    Industrial                         700.             45000.                6.43             0.001132           0.0113
    Coin-Op                          11000.              6000.              0.8571            2.015E-05          0.003166

Other Workers
-------------
    Commercial                      110000.             10000.                1.43            5.591E-05           0.0879
    Industrial                       20000.             10000.                1.43            5.591E-05           0.0160
    Coin-Op                          22000.              6000.              0.8571            2.015E-05          0.006332

Service Users
-------------
    Commercial Dry Clean          50000000.              5.00             0.000714            1.398E-11          9.487E-06
    Coin-Op Dry Clean             25000000.             10.00             0.001429            5.593E-11          1.997E-05
    Coin-Op Laundry               37000000.              3.60             0.000543            8.076E-12          4.269E-06

Urban Residents
---------------
     25 -  200 *                   3700000.              3.50             0.000500            6.851E-12          3.621E-07
    200 -  500 *                  20000000.            0.6000            8.571E-05            2.013E-13          5.753E-08
    500 - 1000 *                  71000000.            0.2000            2.857E-05            2.237E-14          2.269E-08
                                                                                                            -------------
                                                                                              Total              0.3834
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      5.28
```

```
                    OPTION 6

Scaling:   BODY_WEIGHT    Species:  MOUSE     Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =        0.003162
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
    Type of                       Number in            Average Annual Exposure            Incidence           Annual Cases
    Person                    U. S. Population  (micro gms/cubic m)      (mg/kg/day)    (probability/lifetime)  (number/year)
    ------                    ----------------  -------------------      -----------    ----------------------  -------------

Machine Operators
-----------------
    Commercial                      16000.            45000.                 6.43             0.0201               4.60
    Industrial                        700.            45000.                 6.43             0.0201               0.2012
    Coin-Op                         11000.             6000.               0.8571           0.002707               0.4253

Other Workers
-------------
    Commercial                     110000.            10000.                 1.43           0.004507               7.08
    Industrial                      20000.            10000.                 1.43           0.004507               1.29
    Coin-Op                         22000.             6000.               0.8571           0.002707               0.8507

Service Users
-------------
    Commercial Dry Clean         50000000.              5.00             0.000714          2.259E-06               1.61
    Coin-Op Dry Clean            25000000.             10.00             0.001429          4.517E-06               1.61
    Coin-Op Laundry              37000000.              3.80             0.000543          1.717E-06               0.9073

Urban Residents
---------------
      25 -  200 *                 3700000.              3.50             0.000500          1.581E-06               0.0836
     200 -  500 *                20000000.            0.6000            8.571E-05          2.710E-07               0.0774
     500 - 1000 *                71000000.            0.2000            2.857E-05          9.035E-08               0.0916
                                                                                                             -------------
                                                                                             Total              18.83
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     23.73
```

```
              OPTION 6

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       9.524E-06
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime         Expected
       Type of                 Number in             Average Annual Exposure         Incidence          Annual Cases
       Person               U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
       ------               ----------------  -------------------    -----------  ----------------------  -------------

Machine Operators
-----------------
      Commercial                  16000.            45000.               6.43          0.000394             0.0899
      Industrial                    700.            45000.               6.43          0.000394           0.003935
      Coin-Op                     11000.             6000.             0.8571         6.998E-06           0.001100

Other Workers
-------------
      Commercial                 110000.            10000.               1.43         1.943E-05             0.0305
      Industrial                  20000.            10000.               1.43         1.943E-05           0.005552
      Coin-Op                     22000.             6000.             0.8571         6.998E-06           0.002199

Service Users
-------------
      Commercial Dry Clean     50000000.              5.00           0.000714         4.859E-12          3.471E-06
      Coin-Op Dry Clean        25000000.             10.00           0.001429         1.944E-11          6.942E-06
      Coin-Op Laundry          37000000.              3.60           0.000543         2.807E-12          1.484E-06

Urban Residents
---------------
        25 -  200 *             3700000.              3.50           0.000500         2.381E-12          1.259E-07
       200 -  500 *            20000000.            0.6000          8.571E-05         6.998E-14          1.999E-08
       500 - 1000 *            71000000.            0.2000          2.857E-05         7.775E-15          7.886E-09
                                                                                                      -------------
                                                                                    Total               0.1333
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =       5.03
```

```
                    OPTIUN 6

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =        0.000203
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime       Expected
     Type of                   Number in              Average Annual Exposure          Incidence         Annual Cases
     Person                U. S. Population  (micro gms/cubic m)     (mg/kg/day)    (probability/lifetime)  (number/year)
     ------                ----------------  -------------------     -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                  16000.            45000.                 6.43            0.001302              0.2977
     Industrial                    700.            45000.                 6.43            0.001302              0.0130
     Coin-Up                     11000.             6000.               0.8571            0.000174              0.0273

Other workers
-------------
     Commercial                 110000.            10000.                 1.43            0.000290              0.4550
     Industrial                  20000.            10000.                 1.43            0.000290              0.0627
     Coin-Op                     22000.             6000.               0.8571            0.000174              0.0546

Service Users
-------------
     Commercial Dry Clean     50000000.              5.00             0.000714           1.448E-07              0.1034
     Coin-Op Dry Clean        25000000.             10.00             0.001429           2.896E-07              0.1034
     Coin-Op Laundry          37000000.              3.80             0.000543           1.101E-07              0.0582

Urban Residents
---------------
      25 -  200 *              3700000.              3.50             0.000500           1.014E-07              0.005358
     200 -  500 *             20000000.            0.6000            8.571E-05           1.738E-08              0.004965
     500 - 1000 *             71000000.            0.2000            2.857E-05           5.793E-09              0.005875
                                                                                                             --------------
                                                                                           Total                 1.21
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      6.11
```

```
                         OPTION 6

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) =  4.90  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime        Expected
    Type of                        Number in            Average Annual Exposure       Incidence         Annual Cases
    Person                      U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                      ----------------  -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                        16000.           45000.               6.43         3.314E-05          0.007575
    Industrial                          700.           45000.               6.43         3.314E-05          0.000331
    Coin-Op                           11000.            6000.             0.8571         5.887E-07         9.252E-05

Other Workers
-------------
    Commercial                       110000.           10000.               1.43         1.635E-06          0.002570
    Industrial                        20000.           10000.               1.43         1.635E-06          0.000467
    Coin-Op                           22000.            6000.             0.8571         5.887E-07          0.000185

Service Users
-------------
    Commercial Dry Clean           50000000.             5.00           0.000714         4.088E-13         2.920E-07
    Coin-Op Dry Clean              25000000.            10.00           0.001429         1.635E-12         5.641E-07
    Coin-Op Laundry                37000000.             3.80           0.000543         2.362E-13         1.240E-07

Urban Residents
---------------
     25 -  200 *                    3700000.             3.50           0.000500         2.003E-13         1.059E-08
    200 -  500 *                   20000000.           0.6000          8.571E-05         5.887E-15         1.682E-09
    500 - 1000 *                   71000000.           0.2000          2.857E-05         6.542E-16         6.635E-10
                                                                                                        -------------
                                                                                          Total            0.0112
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      4.91
```

```
                        OPTION 7

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
Option cost (millions of dollars) =-13.50  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime      Expected
     Type of                      Number in           Average Annual Exposure         Incidence         Annual Cases
     Person                    U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime) (number/year)
     ------                    ----------------  -------------------    -----------  ---------------------- ------------

Machine Operators
-----------------
     Commercial                      16000.            27000.              3.86            0.1494              34.14
     Industrial                        700.            30150.              4.31            0.1653               1.65
     Coin-Op                         11000.             3300.              0.4714          0.0196               3.08

Other Workers
-------------
     Commercial                     110000.             6000.              0.8571          0.0353              55.49
     Industrial                      20000.             6700.              0.9571          0.0393              11.24
     Coin-Op                         22000.             3300.              0.4714          0.0196               6.15

Service Users
-------------
     Commercial Dry Clean         50000000.             2.80               0.000400        1.675E-05           11.96
     Coin-Op Dry Clean            25000000.             5.90               0.000843        3.535E-05           12.62
     Coin-Op Laundry              37000000.            20.90               0.002986        0.000125            66.19

Urban Residents
---------------
       25 -  200 *                 3700000.             2.00               0.000285        1.198E-05            0.6333
      200 -  500 *                20000000.             0.3420             4.886E-05       2.049E-06            0.5854
      500 - 1000 *                71000000.             0.1140             1.629E-05       6.830E-07            0.6928
                                                                                                          -------------
                                                                                          Total              204.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    190.94
```

```
                      OPTION 7

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =      0.001675
Option cost (millions of dollars) =-13.50  Cost per cancer case (millions of dollars) =  1.00

    Type of                    Number in              Average Annual Exposure             Expected Lifetime      Expected
    Person                 U. S. Population  (micro gms/cubic m)      (mg/kg/day)              Incidence         Annual Cases
    ------                 ----------------  -------------------      -----------     (probability/lifetime)  (number/year)
                                                                                      ----------------------  -------------
Machine Operators
-----------------
     Commercial                  16000.              27000.               3.86                 0.0246              5.63
     Industrial                    700.              30150.               4.31                 0.0306             0.3060
     Coin-Op                     11000.               3300.             0.4714               0.000372             0.0565

Other Workers
-------------
     Commercial                 110000.               6000.             0.8571               0.001230               1.93
     Industrial                  20000.               6700.             0.9571               0.001534             0.4382
     Coin-Op                     22000.               3300.             0.4714               0.000372             0.1170

Service Users
-------------
     Commercial Dry Clean     50000000.               2.80            0.000400              2.681E-10           0.000191
     Coin-Up Dry Clean        25000000.               5.90            0.000843              1.190E-09           0.000425
     Coin-Op Laundry          37000000.              20.90            0.002966              1.494E-06           0.007895

Urban Residents
---------------
      25 -  200 *              3700000.               2.00            0.000285              1.361E-10          7.193E-06
     200 -  500 *             20000000.             0.3420           4.886E-05              3.999E-12          1.143E-06
     500 - 1000 *             71000000.             0.1140           1.629E-05              4.444E-13          4.507E-07
                                                                                                             -------------
* Distance from dry cleaner in meters                                                          Total               8.49

Total cost of option and expected cancer (millions of dollars) =     -5.01
```

```
                         OPTION 7

Scaling: SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =        0.001186
Option cost (millions of dollars) =-13.50  Cost per cancer case (millions of dollars) =  1.00

                                                                                      Expected Lifetime      Expected
     Type of                      Number in            Average Annual Exposure            Incidence         Annual Cases
     Person                    U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                    ----------------  --------------------     -----------   ---------------------- ------------

Machine Operators
-----------------
     Commercial                     16000.              27000.               3.86          0.004563               1.04
     Industrial                       700.              30150.               4.31          0.005094             0.0509
     Coin-Op                        11000.               3300.             0.4714          0.000559             0.0876

Other Workers
-------------
     Commercial                    110000.               6000.             0.8571          0.001016               1.60
     Industrial                     20000.               6700.             0.9571          0.001134             0.3240
     Coin-Op                        22000.               3300.             0.4714          0.000559             0.1756

Service Users
-------------
     Commercial Dry Clean        50000000.                2.80           0.000400          4.742E-07            0.3387
     Coin-Op Dry Clean           25000000.                5.90           0.000843          9.993E-07            0.3569
     Coin-Op Laundry             37000000.               20.90           0.002986          3.540E-06              1.87

Urban Residents
---------------
      25 -  200 *                 3700000.                2.00           0.000285          3.379E-07            0.0179
     200 -  500 *                20000000.              0.3420          4.886E-05          5.793E-08            0.0166
     500 - 1000 *                71000000.              0.1140          1.629E-05          1.931E-08            0.0196
                                                                                                           ------------
                                                                                            Total                  5.90
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -7.60
```

```
                                     OPTION 7
Scaling:  SURFACE_AREA     Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of    43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =-13.50  Cost per cancer case (millions of dollars) =  1.00

  Type of
  Person                     Number in          Average Annual Exposure         Expected Lifetime        Expected
  ------                  U. S. Population   (micro gms/cubic m)  (mg/kg/day)       Incidence          Annual Cases
                          ----------------   -------------------  -----------  (probability/lifetime)  (number/year)
Machine Operators                                                               ----------------------  -------------
-----------------
    Commercial                 16000.             27000.             3.86           0.000408              0.0932
    Industrial                   700.             30150.             4.31           0.000508              0.005082
    Coin-Op                    11000.              3300.             0.4714         6.091E-06             0.000957

Other Workers
-------------
    Commercial                110000.              6000.             0.8571         2.015E-05             0.0317
    Industrial                 20000.              6700.             0.9571         2.509E-05             0.007170
    Coin-Op                    22000.              3300.             0.4714         6.091E-06             0.001914

Service Users
-------------
    Commercial Dry Clean    50000000.              2.80              0.000400       4.385E-12             3.132E-06
    Coin-Op Dry Clean       25000000.              5.90              0.000843       1.947E-11             6.953E-06
    Coin-Op Laundry         37000000.             20.90              0.002986       2.443E-10             0.000129

Urban Residents
---------------
    25 -  200 *              3700000.              2.00              0.000285       2.226E-12             1.177E-07
   200 -  500 *             20000000.              0.3420            4.886E-05      6.542E-14             1.869E-08
   500 - 1000 *             71000000.              0.1140            1.629E-05      7.268E-15             7.372E-09
                                                                                                       -------------
                                                                                          Total          0.1401
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -13.36
```

```
                        OPTION 7

Scaling:   BODY_WEIGHT    Species:  MOUSE     Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) =-13.50  Cost per cancer case (millions of dollars) =  1.00

                                                                          Expected Lifetime      Expected
     Type of                   Number in         Average Annual Exposure       Incidence         Annual Cases
     Person                U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                ----------------  -------------------    -----------  ---------------------  ------------

Machine Operators
-----------------
     Commercial                    16000.            27000.          3.86           0.0121              2.77
     Industrial                      700.            30150.          4.31           0.0135              0.1353
     Coin-Op                       11000.             3300.          0.4714         0.001490            0.2341

Other Workers
-------------
     Commercial                   110000.             6000.          0.8571         0.002707            4.25
     Industrial                    20000.             6700.          0.9571         0.003022            0.8634
     Coin-Op                       22000.             3300.          0.4714         0.001490            0.4682

Service Users
-------------
     Commercial Dry Clean       50000000.             2.80           0.000400       1.265E-06           0.9035
     Coin-Op Dry Clean          25000000.             5.90           0.000843       2.665E-06           0.9519
     Coin-Op Laundry            37000000.            20.90           0.002966       9.441E-06           4.99

Urban Residents
---------------
       25 -  200 *               3700000.             2.00           0.000285       9.012E-07           0.0476
      200 -  500 *              20000000.             0.3420         4.866E-05      1.545E-07           0.0441
      500 - 1000 *              71000000.             0.1140         1.629E-05      5.150E-08           0.0522
                                                                                                    ------------
                                                                                       Total          15.71
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      2.21
```

```
                         OPTION 7

Scaling:   BODY_WEIGHT    Species:  MOUSE     Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332,0 mg/kg/day which implies lambda =       9,524E-06
Option cost (millions of dollars) =-13,50  Cost per cancer case (millions of dollars) =  1,00

                                                                                Expected Lifetime        Expected
      Type of                    Number in                Average Annual Exposure          Incidence           Annual Cases
      Person                 U. S. Population  (micro gms/cubic m)        (mg/kg/day)    (probability/lifetime)  (number/year)
      ------                 ----------------  -------------------        -----------    ---------------------  ------------

Machine Operators
-----------------
     Commercial                     16000,            27000,                 3,86             0,000142             0,0324
     Industrial                       700,            30150,                 4,31             0,000177             0,001767
     Coin-Op                        11000,             3300,               0,4714            2,117E-06             0,000333

Other Workers
-------------
     Commercial                    110000,             6000,               0,8571            6,998E-06             0,0110
     Industrial                     20000,             6700,               0,9571            8,726E-06             0,002493
     Coin-Op                        22000,             3300,               0,4714            2,117E-06             0,000665

Service Users
-------------
     Commercial Dry Clean        50000000,             2,80              0,000400            1,524E-12            1,089E-06
     Coin-Op Dry Clean           25000000,             5,90              0,000843            6,766E-12            2,417E-06
     Coin-Op Laundry             37000000,            20,90              0,002986            8,491E-11            4,488E-05

Urban Residents
---------------
      25 -  200 *                 3700000,             2,00              0,000285            7,736E-13            4,089E-08
     200 -  500 *                20000000,           0,3420             4,886E-05            2,274E-14            6,496E-09
     500 - 1000 *                71000000,           0,1140             1,629E-05            2,526E-15            2,562E-09
                                                                                                               -------------
                                                                                              Total              0,0487
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -13,45
```

```
                    OPTION 7

Scaling:   BODY_WEIGHT    Species:    RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of  253,0 mg/kg/day which implies lambda =        0,000203
Option cost (millions of dollars) =-13,50  Cost per cancer case (millions of dollars) =  1,00

                                                                                 Expected Lifetime        Expected
     Type of                    Number in           Average Annual Exposure           Incidence          Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                    16000.             27000.              3,86            0,000782              0,1787
     Industrial                      700.             30150.              4,31            0,000873            0,008729
     Coin-Op                       11000.              3300.            0,4714          9,555E-05               0,0150

Other Workers
-------------
     Commercial                   110000.              6000.            0,8571            0,000174              0,2730
     Industrial                    20000.              6700.            0,9571            0,000194              0,0554
     Coin-Op                       22000.              3300.            0,4714          9,555E-05               0,0300

Service Users
-------------
     Commercial Dry Clean       50000000.              2,80           0,000400          8,110E-08               0,0579
     Coin-Op Dry Clean          25000000.              5,90           0,000643          1.709E-07               0,0610
     Coin-Op Laundry            37000000.             20,90           0,002986          6,053E-07               0,3200

Urban Residents
---------------
       25 -  200 *               3700000.              2,00           0,000285          5,778E-08             0,003054
      200 -  500 *              20000000.            0,3420          4.866E-05          9,905E-09             0,002830
      500 - 1000 *              71000000.            0,1140          1.629E-05          3,302E-09             0,003349
                                                                                                           -------------
                                                                                        Total                    1,01
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -12,49
```

```
                 OPTION 7

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253,0 mg/kg/day which implies lambda =      8,013E-07
Option cost (millions of dollars) =-13,50  Cost per cancer case (millions of dollars) =  1,00

                                                                                    Expected Lifetime       Expected
     Type of                        Number in          Average Annual Exposure          Incidence          Annual Cases
     Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                     ----------------  -------------------     -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                       16000.            27000.                3,86          1,192E-05            0,002725
    Industrial                         700.            30150.                4,31          1,484E-05            0,000148
    Coin-Op                          11000.             3300.              0,4714          1,781E-07           2,799E-05

Other Workers
-------------
    Commercial                      110000.             6000.              0,8571          5,887E-07            0,000925
    Industrial                       20000.             6700.              0,9571          7,341E-07            0,000210
    Coin-Op                          22000.             3300.              0,4714          1,781E-07           5,597E-05

Service Users
-------------
    Commercial Dry Clean          50000000.              2,80            0,000400          1,282E-13           9,158E-08
    Coin-Op Dry Clean             25000000.              5,90            0,000843          5,693E-13           2,033E-07
    Coin-Op Laundry               37000000.             20,90            0,002986          7,144E-12           3,776E-06

Urban Residents
---------------
     25 -  200 *                   3700000.              2,00            0,000285          6,509E-14           3,440E-09
    200 -  500 *                  20000000.            0,3420           4,886E-05          1,913E-15           5,465E-10
    500 - 1000 *                  71000000.            0,1140           1,629E-05          2,125E-16           2,156E-10
                                                                                                          -------------
                                                                                        Total               0,004096
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -13,50
```

```
                     OPTION 8

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

     Type of                    Number in              Average Annual Exposure           Expected Lifetime       Expected
     Person                  U. S. Population  (micro gms/cubic m)     (mg/kg/day)         Incidence          Annual Cases
     ------                  ----------------  -------------------     -----------   (probability/lifetime)  (number/year)
                                                                                      ----------------------  -------------
Machine Operators
-----------------
    Commercial                    16000.            22050.                3.15             0.1238               28.29
    Industrial                      700.            28800.                4.11             0.1585                1.58
    Coin-Op                       11000.             3300.              0.4714             0.0196                3.08

Other Workers
-------------
    Commercial                   110000.             4900.              0.7000             0.0289               45.46
    Industrial                    20000.             6400.              0.9143             0.0376               10.75
    Coin-Op                       22000.             3300.              0.4714             0.0196                6.15

Service Users
-------------
    Commercial Dry Clean       50000000.             2.45             0.000350           1.466E-05              10.47
    Coin-Op Dry Clean          25000000.             5.90             0.000843           3.535E-05              12.62
    Coin-Op Laundry            37000000.            20.90             0.002986            0.000125              66.19

Urban Residents
---------------
      25 -  200 *               3700000.             1.82             0.000260           1.091E-05              0.5765
     200 -  500 *              20000000.           0.3120            4.457E-05           1.869E-06              0.5341
     500 - 1000 *              71000000.           0.1040            1.486E-05           6.231E-07              0.6320
                                                                                                          -------------
                                                                                          Total                186.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    173.34
```

```
                  OPTION 8

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of    25.0 mg/kg/day which implies lambda =        0.001675
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                     Expected Lifetime       Expected
    Type of                  Number in              Average Annual Exposure              Incidence          Annual Cases
    Person                U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                ----------------  -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                 16000.              22050.                3.15              0.0165               3.77
    Industrial                   700.              28800.                4.11              0.0280             0.2796
    Coin-Up                    11000.               3300.              0.4714            0.000372             0.0585

Other Workers
-------------
    Commercial                110000.               4900.              0.7000            0.000821               1.29
    Industrial                 20000.               6400.              0.9143            0.001400             0.3999
    Coin-Op                    22000.               3300.              0.4714            0.000372             0.1170

Service Users
-------------
    Commercial Dry Clean    50000000.               2.45             0.000350           2.052E-10           0.000147
    Coin-Up Dry Clean       25000000.               5.90             0.000843           1.190E-09           0.000425
    Coin-Up Laundry         37000000.              20.90             0.002986           1.494E-08           0.007895

Urban Residents
---------------
     25 -  200 *             3700000.               1.82             0.000260           1.133E-10          5.987E-06
    200 -  500 *            20000000.             0.3120            4.457E-05           3.328E-12          9.510E-07
    500 - 1000 *            71000000.             0.1040            1.486E-05           3.698E-13          3.751E-07
                                                                                                       -------------
                                                                                            Total               5.92
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -7.08
```

```
                     OPTION 8

Scaling: SURFACE_AREA    Species:    RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime        Expected
   Type of                   Number in              Average Annual Exposure            Incidence          Annual Cases
   Person                 U. S. Population   (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                 ----------------   -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.              22050.               3.15            0.003728               0.8521
    Industrial                     700.              28800.               4.11            0.004866               0.0487
    Coin-Op                      11000.               3300.             0.4714            0.000559               0.0878

Other Workers
-------------
    Commercial                  110000.               4900.             0.7000            0.000830                 1.30
    Industrial                   20000.               6400.             0.9143            0.001083               0.3095
    Coin-Up                      22000.               3300.             0.4714            0.000559               0.1756

Service Users
-------------
    Commercial Dry Clean      50000000.               2.45            0.000350           4.150E-07               0.2964
    Coin-Op Dry Clean         25000000.               5.90            0.000843           9.993E-07               0.3569
    Coin-Op Laundry           37000000.              20.90            0.002986           3.540E-06                 1.87

Urban Residents
---------------
     25 -  200 *               3700000.               1.82            0.000260           3.083E-07               0.0163
    200 -  500 *              20000000.             0.3120           4.457E-05           5.284E-08               0.0151
    500 - 1000 *              71000000.             0.1040           1.486E-05           1.761E-08               0.0179
                                                                                                            -------------
                                                                                        Total                    5.35
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -7.65
```

```
                                        OPTION 8

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      0.003162
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

     Type of                                                                              Expected Lifetime         Expected
     Person                        Number in           Average Annual Exposure                Incidence           Annual Cases
     ------                    U. S. Population   (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)   (number/year)
                               ----------------   -------------------    -----------   ----------------------   -------------
Machine Operators
-----------------
     Commercial                      16000.              22050.             3.15            0.009911                 2.27
     Industrial                        700.              28800.             4.11             0.0129                0.1293
     Coin-Op                         11000.               3300.           0.4714            0.001490               0.2341

Other Workers
-------------
     Commercial                     110000.               4900.           0.7000            0.002211                 3.47
     Industrial                      20000.               6400.           0.9143            0.002687               0.8248
     Coin-Op                         22000.               3300.           0.4714            0.001490               0.4682

Service Users
-------------
     Commercial Dry Clean         50000000.               2.45          0.000350           1.107E-06               0.7905
     Coin-Op Dry Clean            25000000.               5.90          0.000843           2.665E-06               0.9519
     Coin-Op Laundry              37000000.              20.90          0.002486           9.441E-06                 4.99

Urban Residents
---------------
      25 -  200 *                  3700000.               1.82          0.000260           8.221E-07               0.0435
     200 -  500 *                 20000000.             0.3120         4.457E-05           1.409E-07               0.0403
     500 - 1000 *                 71000000.             0.1040         1.486E-05           4.698E-08               0.0477
                                                                                                                -------------
* Distance from dry cleaner in meters                                                         Total                14.26

Total cost of option and expected cancer (millions of dollars) =      1.26
```

```
                    OPTION 8

Scaling:  SURFACE_AREA    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime      Expected
     Type of                   Number in              Average Annual Exposure       Incidence          Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------     -----------  ----------------------  -------------

Machine Operators
-----------------
     Commercial                   16000.            22050.                 3.15          0.000272             0.0621
     Industrial                     700.            28800.                 4.11          0.000464             0.004638
     Coin-Up                      11000.             3300.               0.4714          6.091E-06            0.000957

Other Workers
-------------
     Commercial                  110000.             4900.               0.7000          1.341E-05            0.0211
     Industrial                   20000.             6400.               0.9143          2.289E-05            0.006539
     Coin-Op                      22000.             3300.               0.4714          6.091E-06            0.001914

Service Users
-------------
     Commercial Dry Clean      50000000.             2.45              0.000350          3.357E-12            2.398E-06
     Coin-Up Dry Clean         25000000.             5.90              0.000843          1.947E-11            6.953E-06
     Coin-Up Laundry           37000000.            20.90              0.002986          2.443E-10            0.000129

Urban Residents
---------------
      25 -  200 *               3700000.             1.82              0.000260          1.853E-12            9.792E-08
     200 -  500 *              20000000.           0.3120             4.457E-05          5.444E-14            1.555E-08
     500 - 1000 *              71000000.           0.1040             1.486E-05          6.049E-15            6.136E-09
                                                                                                          -------------
                                                                                             Total          0.0974
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -12.90
```

```
                    OPTION 8

Scaling:  BODY_WEIGHT   Species: MOUSE   Model: QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =     9.524E-06
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

   Type of                                                                            Expected Lifetime       Expected
   Person                   Number in            Average Annual Exposure                   Incidence         Annual Cases
   ------                U. S. Population   (micro gms/cubic m)     (mg/kg/day)    (probability/lifetime)   (number/year)
                         ----------------   -------------------     -----------    ----------------------   -------------
Machine Operators
-----------------
    Commercial                 16000.              22050.                 3.15            9.447E-05              0.0216
    Industrial                   700.              28800.                 4.11            0.000161             0.001612
    Coin-Op                    11000.               3300.               0.4714            2.117E-06            0.000333
Other Workers
-------------
    Commercial                110000.               4900.               0.7000            4.667E-06            0.007334
    Industrial                 20000.               6400.               0.9143            7.962E-06            0.002275
    Coin-Up                    22000.               3300.               0.4714            2.117E-06            0.000665
Service Users
-------------
    Commercial Dry Clean    50000000.                2.45             0.000350            1.167E-12            8.334E-07
    Coin-Op Dry Clean       25000000.                5.90             0.000843            6.766E-12            2.417E-06
    Coin-Op Laundry         37000000.               20.90             0.002986            8.491E-11            4.488E-05
Urban Residents
---------------
     25 -  200 *             3700000.                1.82             0.000260            6.439E-13            3.403E-08
    200 -  500 *            20000000.              0.3120            4.457E-05            1.892E-14            5.406E-09
    500 - 1000 *            71000000.              0.1040            1.486E-05            2.102E-15            2.132E-09
                                                                                                            -------------
* Distance from dry cleaner in meters                                                       Total             0.0339

Total cost of option and expected cancer (millions of dollars) =    -12.97
```

```
                   OPTION 8

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime        Expected
     Type of                       Number in           Average Annual Exposure          Incidence           Annual Cases
     Person                    U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                    ----------------  -------------------      -----------   ----------------------  ------------

Machine Operators
-----------------
     Commercial                      16000.            22050.                3.15           0.000638              0.1459
     Industrial                        700.            28800.                4.11           0.000834            0.008338
     Coin-Op                         11000.             3300.              0.4714          9.555E-05              0.0150

Other Workers
-------------
     Commercial                     110000.             4900.              0.7000           0.000142              0.2230
     Industrial                      20000.             6400.              0.9143           0.000185              0.0530
     Coin-Op                         22000.             3300.              0.4714          9.555E-05              0.0300

Service Users
-------------
     Commercial Dry Clean         50000000.              2.45            0.000350          7.096E-08              0.0507
     Coin-Op Dry Clean            25000000.              5.90            0.000843          1.709E-07              0.0610
     Coin-Op Laundry              37000000.             20.90            0.002986          6.053E-07              0.3200

Urban Residents
---------------
       25 -  200 *                 3700000.              1.82            0.000260          5.271E-08            0.002786
      200 -  500 *                20000000.            0.3120           4.457E-05          9.036E-09            0.002582
      500 - 1000 *                71000000.            0.1040           1.486E-05          3.012E-09            0.003055
                                                                                                            ------------
                                                                                         Total                0.9154

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -12.08
```

```
                                   OPTION 8

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) =-13.00  Cost per cancer case (millions of dollars) =  1.00

     Type of                                                                         Expected Lifetime       Expected
     Person                      Number in            Average Annual Exposure            Incidence         Annual Cases
     ------                   U. S. Population  (micro gms/cubic m)      (mg/kg/day)  (probability/lifetime)  (number/year)
                              ----------------  -------------------      -----------  ----------------------  ------------

Machine Operators
-----------------
      Commercial                    16000.              22050.                3.15          7.951E-06          0.001817
      Industrial                      700.              28800.                4.11          1.359E-05          0.000136
      Coin-Op                       11000.               3300.              0.4714          1.781E-07         2.799E-05

Other Workers
-------------
      Commercial                   110000.               4900.              0.7000          3.927E-07          0.000617
      Industrial                    20000.               6400.              0.9143          6.699E-07          0.000191
      Coin-Op                       22000.               3300.              0.4714          1.781E-07         5.597E-05

Service Users
-------------
      Commercial Dry Clean       50000000.                2.45            0.000350          9.816E-14         7.012E-08
      Coin-Op Dry Clean          25000000.                5.90            0.000843          5.693E-13         2.033E-07
      Coin-Op Laundry            37000000.               20.90            0.002986          7.144E-12         3.776E-06

Urban Residents
---------------
       25 -  200 *                3700000.                1.82            0.000260          5.417E-14         2.863E-09
      200 -  500 *               20000000.              0.3120           4.457E-05          1.592E-15         4.548E-10
      500 - 1000 *               71000000.              0.1040           1.486E-05          1.769E-16         1.794E-10
                                                                                                            -------------
                                                                                             Total           0.002850
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -13.00
```

```
                         OPTION 9

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =          0.0419
Option cost (millions of dollars) =-10.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
    Type of                   Number in             Average Annual Exposure          Incidence         Annual Cases
    Person                U. S. Population   (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                ----------------   -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                 16000.              22050.                 3.15              0.1238              28.29
    Industrial                   700.              28800.                 4.11              0.1585               1.56
    Coin-Op                    11000.               2640.               0.3771              0.0157               2.47

Other Workers
-------------
    Commercial                110000.               4900.               0.7000              0.0289              45.46
    Industrial                 20000.               6400.               0.9143              0.0376              10.75
    Coin-Op                    22000.               2640.               0.3771              0.0157               4.93

Service Users
-------------
    Commercial Dry Clean    50000000.                2.45             0.000350           1.466E-05              10.47
    Coin-Op Dry Clean       25000000.                5.00             0.000714           2.998E-05              10.71
    Coin-Op Laundry         37000000.               16.72             0.002389            0.000100              52.96

Urban Residents
---------------
     25 -  200 *             3700000.                1.68             0.000240           1.007E-05             0.5324
    200 -  500 *            20000000.              0.2880            4.114E-05           1.726E-06             0.4930
    500 - 1000 *            71000000.              0.0960            1.371E-05           5.752E-07             0.5834
                                                                                                         -------------
                                                                                        Total               169.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    159.13
```

```
                                   OPTION 9

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.001675
Option cost (millions of dollars) =-10.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
     Type of                         Number in          Average Annual Exposure       Incidence          Annual Cases
     Person                      U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                      ----------------  -------------------    ----------   ----------------------  ------------

Machine Operators
-----------------
     Commercial                       16000.            22050.              3.15            0.0165                 3.77
     Industrial                         700.            28800.              4.11            0.0280                 0.2796
     Coin-Op                          11000.             2640.              0.3771          0.000238               0.0374

Other Workers
-------------
     Commercial                      110000.             4900.              0.7000          0.000821               1.29
     Industrial                       20000.             6400.              0.9143          0.001400               0.3999
     Coin-Op                          22000.             2640.              0.3771          0.000238               0.0749

Service Users
-------------
     Commercial Dry Clean          50000000.               2.45             0.000350        2.052E-10           0.000147
     Coin-Op Dry Clean             25000000.               5.00             0.000714        8.548E-10           0.000305
     Coin-Op Laundry               37000000.              16.72             0.002389        9.559E-09           0.005053

Urban Residents
---------------
       25 -  200 *                  3700000.               1.68             0.000240        9.651E-11           5.101E-06
      200 -  500 *                 20000000.               0.2880           4.114E-05       2.836E-12           8.103E-07
      500 - 1000 *                 71000000.               0.0960           1.371E-05       3.151E-13           3.196E-07
                                                                                                           -------------
                                                                                         Total                 5.86
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -4.24
```

```
                    OPTION 9

Scaling: SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =        0.001186
Option cost (millions of dollars) =-10.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime        Expected
   Type of                     Number in               Average Annual Exposure            Incidence         Annual Cases
   Person                   U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                   ----------------  -------------------     -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                   16000.            22050.                3.15            0.003728              0.8521
     Industrial                     700.            26800.                4.11            0.004866              0.0487
     Coin-Op                      11000.             2640.              0.3771            0.000447              0.0702

Other Workers
-------------
     Commercial                  110000.             4900.              0.7000            0.000830                1.30
     Industrial                   20000.             6400.              0.9143            0.001083              0.3095
     Coin-Op                      22000.             2640.              0.3771            0.000447              0.1405

Service Users
-------------
     Commercial Dry Clean      50000000.              2.45            0.000350           4.150E-07              0.2964
     Coin-Op Dry Clean         25000000.              5.00            0.000714           8.469E-07              0.3025
     Coin-Op Laundry           37000000.             16.72            0.002389           2.832E-06                1.50

Urban Residents
---------------
      25 -  200 *               3700000.              1.68            0.000240           2.845E-07              0.0150
     200 -  500 *              20000000.            0.2880           4.114E-05           4.878E-08              0.0139
     500 - 1000 *              71000000.            0.0960           1.371E-05           1.626E-08              0.0165
                                                                                                           -------------
                                                                                             Total                4.87
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -5.23
```

```
                              OPTION 9

Scaling: SURFACE_AREA    Species:    RAT    Model: QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       2.740E-05
Option cost (millions of dollars) =-10.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime        Expected
     Type of                      Number in              Average Annual Exposure           Incidence            Annual Cases
     Person                    U. S. Population   (micro gms/cubic m)      (mg/kg/day)    (probability/lifetime)  (number/year)
     ------                    ----------------   -------------------      -----------    ----------------------  -------------

Machine Operators
-----------------
      Commercial                      16000.             22050.              3.15            0.000272             0.0621
      Industrial                        700.             28800.              4.11            0.000464           0.004638
      Coin-Op                         11000.              2640.            0.3771           3.898E-06           0.000613

Other Workers
-------------
      Commercial                     110000.              4900.            0.7000           1.341E-05             0.0211
      Industrial                      20000.              6400.            0.9143           2.289E-05           0.006539
      Coin-Op                         22000.              2640.            0.3771           3.898E-06           0.001225

Service Users
-------------
      Commercial Dry Clean         50000000.               2.45          0.000350           3.357E-12          2.398E-06
      Coin-Op Dry Clean            25000000.               5.00          0.000714           1.398E-11          4.994E-06
      Coin-Op Laundry              37000000.              16.72          0.002389           1.564E-10          8.264E-05

Urban Residents
---------------
       25 -  200 *                  3700000.               1.68          0.000240           1.579E-12          8.344E-08
      200 -  500 *                 20000000.             0.2880         4.114E-05           4.639E-14          1.325E-08
      500 - 1000 *                 71000000.             0.0960         1.371E-05           5.154E-15          5.226E-09
                                                                                                             -------------
* Distance from dry cleaner in meters                                                         Total             0.0963

Total cost of option and expected cancer (millions of dollars) =    -10.00
```

```
                         OPTION 9

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:      LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =        0.003162
Option cost (millions of dollars) =-10.10  Cost per cancer case (millions of dollars) =  1.00

   Type of                                                                      Expected Lifetime       Expected
   Person                   Number in         Average Annual Exposure              Incidence         Annual Cases
   ------               U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
                        ----------------  -------------------     -----------  ----------------------  -------------
Machine Operators
-----------------
    Commercial               16000.            22050.                 3.15            0.009911               2.27
    Industrial                 700.            28800.                 4.11              0.0129             0.1293
    Coin-Op                  11000.             2640.               0.3771            0.001192             0.1873
Other Workers
-------------
    Commercial              110000.             4900.               0.7000            0.002211               3.47
    Industrial               20000.             6400.               0.9143            0.002887             0.8248
    Coin-Op                  22000.             2640.               0.3771            0.001192             0.3746
Service Users
-------------
    Commercial Dry Clean  50000000.              2.45             0.000350           1.107E-06             0.7905
    Coin-Up Dry Clean     25000000.              5.00             0.000714           2.259E-06             0.8067
    Coin-Op Laundry       37000000.             16.72             0.002389           7.553E-06               3.99
Urban Residents
---------------
     25 -  200 *           3700000.              1.68             0.000240           7.589E-07             0.0401
    200 -  500 *          20000000.            0.2880            4.114E-05           1.301E-07             0.0372
    500 - 1000 *          71000000.            0.0960            1.371E-05           4.337E-08             0.0440
                                                                                                    -------------
* Distance from dry cleaner in meters                                                    Total              12.97

Total cost of option and expected cancer (millions of dollars) =      2.87
```

```
              OPTION 9

Scaling:   BODY_WEIGHT    Species:  MOUSE     Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) =-10.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime       Expected
   Type of                        Number in             Average Annual Exposure         Incidence          Annual Cases
   Person                      U. S. Population   (micro gms/cubic m)   (mg/kg/day)  (probability/lifetime)  (number/year)
   ------                      ---------------    -------------------   -----------  ---------------------  ------------

Machine Operators
-----------------
     Commercial                       16000.             22050.             3.15        9.447E-05              0.0216
     Inoustrial                         700.             28800.             4.11         0.000161              0.001612
     Coin-Up                          11000.              2640.           0.3771        1.355E-06              0.000213

Other Workers
-------------
     Commercial                      110000.              4900.           0.7000        4.667E-06              0.007334
     Industrial                       20000.              6400.           0.9143        7.962E-06              0.002275
     Coin-Op                          22000.              2640.           0.3771        1.355E-06              0.000426

Service Users
-------------
     Commercial Dry Clean          50000000.              2.45          0.000350        1.167E-12              8.334E-07
     Coin-Op Dry Clean             25000000.              5.00          0.000714        4.859E-12              1.736E-06
     Coin-Op Laundry               37000000.             16.72          0.002389        5.434E-11              2.872E-05

Urban Residents
---------------
      25 -  200 *                   3700000.              1.68          0.000240        5.486E-13              2.900E-08
     200 -  500 *                  20000000.            0.2880         4.114E-05        1.612E-14              4.606E-09
     500 - 1000 *                  71000000.            0.0960         1.371E-05        1.791E-15              1.817E-09
                                                                                                           -------------
                                                                                          Total                 0.0335

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -10.07
```

```
                        OPTION 9

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) =-10.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime      Expected
   Type of                        Number in           Average Annual Exposure          Incidence          Annual Cases
   Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
   ------                     ----------------  -------------------     -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                     16000.            22050.                3.15           0.000638             0.1459
    Industrial                       700.            28800.                4.11           0.000834           0.008338
    Coin-Op                        11000.             2640.              0.3771          7.647E-05             0.0120

Other Workers
-------------
    Commercial                    110000.             4900.              0.7000           0.000142             0.2230
    Industrial                     20000.             6400.              0.9143           0.000185             0.0530
    Coin-Op                        22000.             2640.              0.3771          7.647E-05             0.0240

Service Users
-------------
    Commercial Dry Clean        50000000.              2.45            0.000350          7.096E-08             0.0507
    Coin-Up Dry Clean           25000000.              5.00            0.000714          1.448E-07             0.0517
    Coin-Op Laundry             37000000.             16.72            0.002389          4.843E-07             0.2560

Urban Residents
---------------
     25 -  200 *                 3700000.              1.68            0.000240          4.866E-08           0.002572
    200 -  500 *                20000000.            0.2880           4.114E-05          8.341E-09           0.002383
    500 - 1000 *                71000000.            0.0960           1.371E-05          2.780E-09           0.002820
                                                                                                          -------------
                                                                                          Total               0.8324
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -9.27
```

```
                OPTION 9

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) =-10,10  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime         Expected
   Type of                         Number in           Average Annual Exposure           Incidence           Annual Cases
   Person                      U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
   ------                      ----------------  -------------------    -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                       16000.              22050.               3.15          7.951E-06           0.001817
    Industrial                         700.              28800.               4.11          1.359E-05           0.000136
    Coin-Op                          11000.               2640.             0.3771          1.140E-07          1.791E-05

Other Workers
-------------
    Commercial                      110000.               4900.             0.7000          3.927E-07           0.000617
    Industrial                       20000.               6400.             0.9143          6.699E-07           0.000191
    Coin-Up                          22000.               2640.             0.3771          1.140E-07          3.582E-05

Service Users
-------------
    Commercial Dry Clean         50000000.                2.45           0.000350          9.816E-14          7.012E-08
    Coin-Op Dry Clean            25000000.                5.00           0.000714          4.086E-13          1.460E-07
    Coin-Op Laundry              37000000.               16.72           0.002389          4.572E-12          2.417E-06

Urban Residents
---------------
     25 -  200 *                  3700000.                1.68           0.000240          4.616E-14          2.440E-09
    200 -  500 *                 20000000.              0.2880          4.114E-05          1.356E-15          3.876E-10
    500 - 1000 *                 71000000.              0.0960          1.371E-05          1.507E-16          1.529E-10
                                                                                                         -------------
                                                                                          Total            0.002618
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    -10,10
```

```
                 OPTION 10

Scaling: SURFACE_AREA   Species: MOUSE   Model:    LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
Option cost (millions of dollars) = -4.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime      Expected
     Type of                    Number in           Average Annual Exposure          Incidence        Annual Cases
     Person                  U. S. Population  (micro gms/cubic m)   (mg/kg/day)  (probability/lifetime) (number/year)
     ------                  ----------------  -------------------   -----------  ---------------------- -------------

Machine Operators
-----------------
     Commercial                  16000.             14400.              2.06           0.0827             18.89
     Industrial                    700.             28800.              4.11           0.1585              1.58
     Coin-Op                     11000.              3300.              0.4714         0.0196              3.08

Other Workers
-------------
     Commercial                 110000.              4900.              0.7000         0.0289             45.46
     Industrial                  20000.              6400.              0.9143         0.0376             10.75
     Coin-Op                     22000.              3300.              0.4714         0.0196              6.15

Service Users
-------------
     Commercial Dry Clean     50000000.                2.45             0.000350       1.466E-05          10.47
     Coin-Op Dry Clean        25000000.                5.90             0.000843       3.535E-05          12.62
     Coin-Op Laundry          37000000.               20.90             0.002986       0.000125           66.19

Urban Residents
---------------
      25 -  200 *              3700000.                1.82             0.000260       1.091E-05           0.5765
     200 -  500 *             20000000.                0.3120           4.457E-05      1.869E-06           0.5341
     500 - 1000 *             71000000.                0.1040           1.486E-05      6.231E-07           0.6320
                                                                                                      -------------
                                                                                         Total            177.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    172.65
```

```
                    OPTION 10

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of    25.0 mg/kg/day which implies lambda =        0.001675
Option cost (millions of dollars) = -4.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime        Expected
     Type of                  Number in           Average Annual Exposure            Incidence          Annual Cases
     Person                U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                ----------------  -------------------     -----------   ---------------------- -------------

Machine Operators
-----------------
     Commercial                  16000.             14400.               2.06            0.007065              1.61
     Industrial                    700.             28800.               4.11              0.0280            0.2796
     Coin-Op                     11000.              3300.             0.4714            0.000372            0.0585

Other Workers
-------------
     Commercial                 110000.              4900.             0.7000            0.000821              1.29
     Industrial                  20000.              6400.             0.9143            0.001400            0.3999
     Coin-Op                     22000.              3300.             0.4714            0.000372            0.1170

Service Users
-------------
     Commercial Dry Clean     50000000.              2.45            0.000350           2.052E-10          0.000147
     Coin-Op Dry Clean        25000000.              5.90            0.000843           1.190E-09          0.000425
     Coin-Op Laundry          37000000.             20.90            0.002986           1.494E-08          0.007695

Urban Residents
---------------
      25 -  200 *              3700000.              1.82            0.000260           1.133E-10         5.987E-06
     200 -  500 *             20000000.            0.3120           4.457E-05           3.328E-12         9.510E-07
     500 - 1000 *             71000000.            0.1040           1.486E-05           3.698E-13         3.751E-07
                                                                                                        -------------
* Distance from dry cleaner in meters                                                      Total             3.77

Total cost of option and expected cancer (millions of dollars) =     -0.53
```

```
                       OPTION 10

Scaling: SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      0.001186
Option cost (millions of dollars) = -4.30  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime       Expected
      Type of                     Number in           Average Annual Exposure      Incidence         Annual Cases
      Person                   U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
      ------                   ----------------  -------------------    -----------  ----------------------  ------------

Machine Operators
-----------------
     Commercial                      16000.            14400.             2.06          0.002436             0.5568
     Industrial                        700.            26800.             4.11          0.004666             0.0487
     Coin-Op                         11000.             3300.           0.4714          0.000559             0.0878

Other Workers
-------------
     Commercial                     110000.             4900.           0.7000          0.000830               1.30
     Industrial                      20000.             6400.           0.9143          0.001083             0.3095
     Coin-Op                         22000.             3300.           0.4714          0.000559             0.1756

Service Users
-------------
     Commercial Dry Clean         50000000.              2.45         0.000350         4.150E-07             0.2964
     Coin-Op Dry Clean            25000000.              5.90         0.000843         9.993E-07             0.3569
     Coin-Op Laundry              37000000.             20.90         0.002986         3.540E-06               1.87

Urban Residents
---------------
       25 -  200 *                 3700000.              1.82         0.000260         3.083E-07             0.0163
      200 -  500 *                20000000.            0.3120        4.457E-05         5.284E-08             0.0151
      500 - 1000 *                71000000.            0.1040        1.486E-05         1.761E-08             0.0179
                                                                                                        -------------
                                                                                          Total                5.06
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      0.76
```

```
                  OPTION 10

Scaling:  SURFACE_AREA    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) = -4.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime     Expected
   Type of                        Number in           Average Annual Exposure           Incidence        Annual Cases
   Person                      U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                      ----------------  -------------------      -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                      16000.              14400.              2.06          0.000116            0.0265
    Industrial                        700.              28800.              4.11          0.000464          0.004638
    Coin-Op                         11000.               3300.            0.4714         6.091E-06          0.000957

Other Workers
-------------
    Commercial                     110000.               4900.            0.7000         1.341E-05            0.0211
    Industrial                      20000.               6400.            0.9143         2.289E-05          0.006539
    Coin-Op                         22000.               3300.            0.4714         6.091E-06          0.001914

Service Users
-------------
    Commercial Dry Clean         50000000.                2.45          0.000350         3.357E-12         2.398E-06
    Coin-Op Dry Clean            25000000.                5.90          0.000843         1.947E-11         6.953E-06
    Coin-Op Laundry              37000000.               20.90          0.002986         2.443E-10          0.000129

Urban Residents
---------------
     25 -  200 *                  3700000.                1.82          0.000260         1.853E-12         9.792E-08
    200 -  500 *                 20000000.              0.3120         4.457E-05         5.444E-14         1.555E-08
    500 - 1000 *                 71000000.              0.1040         1.486E-05         6.049E-15         6.136E-09
                                                                                                        ------------
                                                                                           Total          0.0618
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -4.24
```

```
                          OPTION 10

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332,0 mg/kg/day which implies lambda =       0,005162
Option cost (millions of dollars) = -4,30  Cost per cancer case (millions of dollars) =  1,00

                                                                                    Expected Lifetime          Expected
     Type of                        Number in          Average Annual Exposure          Incidence           Annual Cases
     Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                     ---------------  ------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                      16000.              14400.              2,06          0,006484                 1,48
    Industrial                        700.              28800.              4,11            0,0129               0,1293
    Coin-Op                         11000.               3300.            0,4714          0,001490               0,2341

Other workers
-------------
    Commercial                     110000.               4900.            0,7000          0,002211                 3,47
    Industrial                      20000.               6400.            0,9143          0,002887               0,8248
    Coin-Op                         22000.               3300.            0,4714          0,001490               0,4682

Service Users
-------------
    Commercial Dry Clean         50000000.               2,45           0,000350         1,107E-06               0,7905
    Coin-Op Dry Clean            25000000.               5,90           0,000843         2,665E-06               0,9519
    Coin-Op Laundry              37000000.              20,90           0,002986         9,441E-06                 4,99

Urban Residents
---------------
     25 -  200 *                  3700000.               1,82           0,000260         8,221E-07               0,0435
    200 -  500 *                 20000000.             0,3120          4,457E-05         1,409E-07               0,0403
    500 - 1000 *                 71000000.             0,1040          1,486E-05         4,698E-08               0,0477
                                                                                                           ------------
                                                                                          Total                   13,48
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      9,18
```

```
                      OPTION 10

Scaling:  BODY_WEIGHT    Species:  MUUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) = -4.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime      Expected
  Type of                        Number in           Average Annual Exposure           Incidence        Annual Cases
  Person                     U. S. Population   (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
  ------                     ----------------   -------------------    -----------   ---------------------  ------------

Machine Operators
-----------------
    Commercial                      16000.            14400.               2.06          4.029E-05          0.009210
    Industrial                        700.            28800.               4.11          0.000161           0.001612
    Coin-Op                         11000.             3300.             0.4714          2.117E-06          0.000333

Other Workers
-------------
    Commercial                     110000.             4900.             0.7000          4.667E-06          0.007334
    Industrial                      20000.             6400.             0.9143          7.962E-06          0.002275
    Coin-Op                         22000.             3300.             0.4714          2.117E-06          0.000665

Service Users
-------------
    Commercial Dry Clean         50000000.             2.45            0.000350          1.167E-12          8.334E-07
    Coin-Up Dry Clean            25000000.             5.90            0.000843          6.766E-12          2.417E-06
    Coin-Op Laundry              37000000.            20.90            0.002986          8.491E-11          4.488E-05

Urban Residents
---------------
       25 -  200 *                3700000.             1.82            0.000260          6.439E-13          3.403E-08
      200 -  500 *               20000000.           0.3120           4.457E-05          1.892E-14          5.406E-09
      500 - 1000 *               71000000.           0.1040           1.486E-05          2.102E-15          2.132E-09
                                                                                                        -------------
                                                                                            Total          0.0215
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -4.28
```

```
                 OPTION 10

Scaling:   BODY_WEIGHT    Species:    RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) = -4.30  Cost per cancer case (millions of dollars) =  1.00

                                                                                     Expected Lifetime       Expected
     Type of                      Number in              Average Annual Exposure         Incidence          Annual Cases
     Person                   U. S. Population   (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                   ----------------   -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                      16000.              14400.               2.06           0.000417             0.0953
    Industrial                        700.              28800.               4.11           0.000634           0.008338
    Coin-Op                         11000.               3300.             0.4714          9.555E-05             0.0150

Other Workers
-------------
    Commercial                     110000.               4900.             0.7000           0.000142             0.2230
    Industrial                      20000.               6400.             0.9143           0.000165             0.0530
    Coin-Op                         22000.               3300.             0.4714          9.555E-05             0.0300

Service Users
-------------
    Commercial Dry Clean         50000000.               2.45            0.000350          7.096E-08             0.0507
    Coin-Op Dry Clean            25000000.               5.90            0.000843          1.709E-07             0.0610
    Coin-Op Laundry              37000000.              20.90            0.002986          6.053E-07             0.3200

Urban Residents
---------------
     25 -  200 *                  3700000.               1.82            0.000260          5.271E-08           0.002786
    200 -  500 *                 20000000.             0.3120           4.457E-05          9.036E-09           0.002582
    500 - 1000 *                 71000000.             0.1040           1.486E-05          3.012E-09           0.003055
                                                                                                          ------------
                                                                                            Total             0.8648
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -3.44
```

```
                              OPTION 10

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) = -4.30  Cost per cancer case (millions of dollars) =  1.00

     Type of                              Number in           Average Annual Exposure           Expected Lifetime          Expected
     Person                            U. S. Population  (micro gms/cubic m)      (mg/kg/day)        Incidence            Annual Cases
     ------                            ----------------  -------------------      -----------  (probability/lifetime)  (number/year)
                                                                                               ----------------------  -------------
Machine Operators
-----------------
    Commercial                              16000.             14400.                2.06          3.391E-06              0.000775
    Industrial                                700.             20800.                4.11          1.359E-05              0.000136
    Coin-Op                                 11000.              3300.              0.4714          1.781E-07             2.799E-05

Other Workers
-------------
    Commercial                             110000.              4900.              0.7000          3.927E-07              0.000617
    Industrial                              20000.              6400.              0.9143          6.699E-07              0.000191
    Coin-Op                                 22000.              3300.              0.4714          1.781E-07             5.597E-05

Service Users
-------------
    Commercial Dry Clean                 50000000.              2.45             0.000350          9.816E-14             7.012E-08
    Coin-Op Dry Clean                    25000000.              5.90             0.000843          5.693E-13             2.033E-07
    Coin-Op Laundry                      37000000.             20.90             0.002986          7.144E-12             3.776E-06

Urban Residents
---------------
     25 -  200 *                          3700000.              1.82             0.000260          5.417E-14             2.863E-09
    200 -  500 *                         20000000.            0.3120            4.457E-05          1.592E-15             4.548E-10
    500 - 1000 *                         71000000.            0.1040            1.486E-05          1.769E-16             1.794E-10
                                                                                                                     -------------
* Distance from dry cleaner in meters                                                                     Total       0.001007

Total cost of option and expected cancer (millions of dollars) =     -4.30
```

```
                                     OPTION 11

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =          0.0419
Option cost (millions of dollars) = -8.10  Cost per cancer case (millions of dollars) =  1.00

                                                                              Expected Lifetime        Expected
     Type of                  Number in             Average Annual Exposure       Incidence          Annual Cases
     Person               U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
     ------               ----------------  ------------------      ----------   ---------------------   ------------

Machine Operators
-----------------
     Commercial                 16000.             22050.              3.15          0.1238              28.29
     Industrial                   700.             28800.              4.11          0.1585               1.58
     Coin-Op                    11000.              3300.            0.4714          0.0196               3.08

Other Workers
-------------
     Commercial                110000.              4900.            0.7000          0.0289              45.46
     Industrial                 20000.              6400.            0.9143          0.0376              10.75
     Coin-Op                    22000.              3300.            0.4714          0.0196               6.15

Service Users
-------------
     Commercial Dry Clean    50000000.              2.45           0.000350        1.466E-05            10.47
     Coin-Up Dry Clean       25000000.              5.90           0.000843        3.535E-05            12.62
     Coin-Op Laundry         37000000.              2.09           0.000299        1.252E-05             6.62

Urban Residents
---------------
       25 -  200 *            3700000.              1.82           0.000260        1.091E-05            0.5765
      200 -  500 *           20000000.            0.3120          4.457E-05        1.869E-06            0.5341
      500 - 1000 *           71000000.            0.1040          1.466E-05        6.231E-07            0.6320
                                                                                                      ------------
                                                                                   Total                127.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    118.67
```

```
                    OPTION 11

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =       0.001675
Option cost (millions of dollars) = -8.10  Cost per cancer case (millions of dollars) =  1.00
                                                                              Expected Lifetime         Expected
   Type of                     Number in            Average Annual Exposure        Incidence          Annual Cases
   Person                   U. S. Population   (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                   ----------------   -------------------     -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.              22050.               3.15              0.0165              3.77
    Industrial                     700.              28800.               4.11              0.0280              0.2796
    Coin-Op                      11000.               3300.             0.4714              0.000372            0.0585

Other Workers
-------------
    Commercial                  110000.               4900.             0.7000              0.000821            1.29
    Industrial                   20000.               6400.             0.9143              0.001400            0.3999
    Coin-Op                      22000.               3300.             0.4714              0.000372            0.1170

Service Users
-------------
    Commercial Dry Clean      50000000.               2.45            0.000350            2.052E-10           0.000147
    Coin-Op Dry Clean         25000000.               5.90            0.000843            1.190E-09           0.000425
    Coin-Op Laundry           37000000.               2.09            0.000299            1.494E-10           7.895E-05

Urban Residents
---------------
    .25 -  200 *               3700000.               1.82            0.000260            1.133E-10           5.987E-06
    200 -  500 *              20000000.             0.3120            4.457E-05           3.328E-12           9.510E-07
    500 - 1000 *              71000000.             0.1040            1.486E-05           3.698E-13           3.751E-07
                                                                                                          -------------
                                                                                            Total              5.91

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -2.19
```

```
                    OPTION 11

Scaling: SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) = -8.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime       Expected
    Type of                          Number in             Average Annual Exposure      Incidence          Annual Cases
    Person                       U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
    ------                       ----------------  -------------------    -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                        16000.            22050.               3.15          0.003728              0.8521
    Industrial                          700.            28800.               4.11          0.004866              0.0487
    Coin-Op                           11000.             3300.             0.4714          0.000559              0.0878

Other Workers
-------------
    Commercial                       110000.             4900.             0.7000          0.000830                1.30
    Industrial                        20000.             6400.             0.9143          0.001083              0.3095
    Coin-Op                           22000.             3300.             0.4714          0.000559              0.1756

Service Users
-------------
    Commercial Dry Clean           50000000.              2.45           0.000350         4.150E-07              0.2964
    Coin-Op Dry Clean              25000000.              5.90           0.000843         9.993E-07              0.3569
    Coin-Op Laundry                37000000.              2.09           0.000299         3.540E-07              0.1871

Urban Residents
---------------
     25 -  200 *                    3700000.              1.82           0.000260         3.083E-07              0.0163
    200 -  500 *                   20000000.            0.3120          4.457E-05         5.284E-08              0.0151
    500 - 1000 *                   71000000.            0.1040          1.486E-05         1.761E-08              0.0179
                                                                                                          -------------
                                                                                         Total                 3.67

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -4.43
```

```
                    OPTION 11

Scaling: SURFACE_AREA    Species:    RAT    Model: QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) = -8.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime        Expected
   Type of                    Number in            Average Annual Exposure             Incidence           Annual Cases
   Person                 U. S. Population  (micro gms/cubic m)       (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                 ----------------  -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                 16000.            22050.                  3.15          0.000272              0.0621
     Industrial                   700.            28800.                  4.11          0.000464            0.004638
     Coin-Op                    11000.             3300.                0.4714         6.091E-06            0.000957

Other Workers
-------------
     Commercial                110000.             4900.                0.7000         1.341E-05              0.0211
     Industrial                 20000.             6400.                0.9143         2.289E-05            0.006539
     Coin-Op                    22000.             3300.                0.4714         6.091E-06            0.001914

Service Users
-------------
     Commercial Dry Clean    50000000.              2.45              0.000350         3.357E-12           2.398E-06
     Coin-Op Dry Clean       25000000.              5.90              0.000843         1.947E-11           6.953E-06
     Coin-Op Laundry         37000000.              2.09              0.000299         2.443E-12           1.291E-06

Urban Residents
---------------
      25 -  200 *             3700000.              1.82              0.000260         1.853E-12           9.792E-08
     200 -  500 *            20000000.            0.3120             4.457E-05         5.444E-14           1.555E-08
     500 - 1000 *            71000000.            0.1040             1.486E-05         6.049E-15           6.136E-09
                                                                                                       -------------
                                                                                          Total               0.0973
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -8.00
```

```
                        OPTION 11

Scaling:  BODY_WEIGHT    Species: MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of  332,0 mg/kg/day which implies lambda =      0,003162
Option cost (millions of dollars) = -8,10  Cost per cancer case (millions of dollars) =  1,00

                                                                               Expected Lifetime      Expected
     Type of                  Number in          Average Annual Exposure           Incidence        Annual Cases
     Person                U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                ---------------   ------------------     -----------   ---------------------  -----------

Machine Operators
-----------------
    Commercial                  16000.           22050.               3,15          0,009911             2,27
    Industrial                    700.           28800.               4,11            0,0129           0,1293
    Coin-Op                     11000.            3300.             0,4714          0,001490           0,2341

Other Workers
-------------
    Commercial                 110000.            4900.             0,7000          0,002211             3,47
    Industrial                  20000.            6400.             0,9143          0,002887           0,6248
    Coin-Op                     22000.            3300.             0,4714          0,001490           0,4682

Service Users
-------------
    Commercial Dry Clean     50000000.            2,45            0,000350         1,107E-06           0,7905
    Coin-Op Dry Clean        25000000.            5,90            0,000643         2,665E-06           0,9519
    Coin-Op Laundry          37000000.            2,09            0,000299         9,441E-07           0,4990

Urban Residents
---------------
     25 -  200 *              3700000.            1.82            0,000260         8,221E-07           0,0435
    200 -  500 *             20000000.          0,3120           4,457E-05         1,409E-07           0,0403
    500 - 1000 *             71000000.          0,1040           1,486E-05         4,698E-08           0,0477
                                                                                                    ------------
* Distance from dry cleaner in meters                                                  Total               9,77

Total cost of option and expected cancer (millions of dollars) =      1,67
```

```
                         OPTION 11

Scaling:  BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) = -8.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime        Expected
     Type of                    Number in              Average Annual Exposure          Incidence          Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)      (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------      -----------  ----------------------  -------------

Machine Operators
-----------------
     Commercial                    16000.             22050.              3.15           9.447E-05              0.0216
     Industrial                      700.             28800.              4.11           0.000161             0.001612
     Coin-Op                       11000.              3300.            0.4714           2.117E-06            0.000333

Other Workers
-------------
     Commercial                   110000.              4900.            0.7000           4.667E-06            0.007334
     Industrial                    20000.              6400.            0.9143           7.962E-06            0.002275
     Coin-Op                       22000.              3300.            0.4714           2.117E-06            0.000665

Service Users
-------------
     Commercial Dry Clean       50000000.               2.45          0.000350           1.167E-12           8.334E-07
     Coin-Op Dry Clean          25000000.               5.90          0.000843           6.766E-12           2.417E-06
     Coin-Op Laundry            37000000.               2.09          0.000299           8.491E-13           4.488E-07

Urban Residents
---------------
       25 -  200 *               3700000.               1.82          0.000260           6.439E-13           3.403E-08
      200 -  500 *              20000000.             0.3120         4.457E-05           1.892E-14           5.406E-09
      500 - 1000 *              71000000.             0.1040         1.486E-05           2.102E-15           2.132E-09
                                                                                                        -------------
                                                                                       Total                0.0338
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -8.07
```

```
                              OPTION 11

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) = -8.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime         Expected
    Type of                       Number in              Average Annual Exposure        Incidence            Annual Cases
    Person                    U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                    ----------------  -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
     Commercial                    16000.             22050.               3.15            0.000638              0.1459
     Industrial                      700.             28800.               4.11            0.000834            0.008338
     Coin-Op                       11000.              3300.             0.4714           9.555E-05              0.0150

Other Workers
-------------
     Commercial                   110000.              4900.             0.7000            0.000142              0.2230
     Industrial                    20000.              6400.             0.9143            0.000185              0.0530
     Coin-Op                       22000.              3300.             0.4714           9.555E-05              0.0300

Service Users
-------------
     Commercial Dry Clean      50000000.               2.45           0.000350           7.096E-08              0.0507
     Coin-Op Dry Clean         25000000.               5.90           0.000843           1.709E-07              0.0610
     Coin-Op Laundry           37000000.               2.09           0.000299           6.053E-08              0.0320

Urban Residents
---------------
      25 -  200 *               3700000.               1.82           0.000260           5.271E-08            0.002786
     200 -  500 *              20000000.             0.3120          4.457E-05           9.036E-09            0.002582
     500 - 1000 *              71000000.             0.1040          1.486E-05           3.012E-09            0.003055
                                                                                                          -------------
                                                                                          Total               0.6274
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -7.47
```

```
                              OPTION 11

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) = -8.10  Cost per cancer case (millions of dollars) =  1.00

                                                                                          Expected Lifetime          Expected
     Type of                          Number in             Average Annual Exposure           Incidence           Annual Cases
     Person                        U. S. Population   (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                        ----------------   -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                         16000.              22050.                3.15            7.951E-06             0.001817
     Industrial                           700.              28800.                4.11            1.359E-05             0.000136
     Coin-Op                            11000.               3300.              0.4714            1.781E-07            2.799E-05

Other Workers
-------------
     Commercial                        110000.               4900.              0.7000            3.927E-07             0.000617
     Industrial                         20000.               6400.              0.9143            6.699E-07             0.000191
     Coin-Op                            22000.               3300.              0.4714            1.781E-07            5.597E-05

Service Users
-------------
     Commercial Dry Clean            50000000.                2.45            0.000350            9.816E-14            7.012E-08
     Coin-Op Dry Clean               25000000.                5.90            0.000843            5.693E-13            2.033E-07
     Coin-Op Laundry                 37000000.                2.09            0.000299            7.144E-14            3.776E-08

Urban Residents
---------------
       25 -  200 *                    3700000.                1.82            0.000260            5.417E-14            2.663E-09
      200 -  500 *                   20000000.              0.3120           4.457E-05            1.592E-15            4.548E-10
      500 - 1000 *                   71000000.              0.1040           1.486E-05            1.769E-16            1.794E-10
                                                                                                                -------------
                                                                                              Total               0.002846

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -8.10
```

```
                    OPTION 12

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.0419
Option cost (millions of dollars) = -1.40  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
   Type of                         Number in             Average Annual Exposure           Incidence          Annual Cases
   Person                       U. S. Population   (micro gms/cubic m)        (mg/kg/day)    (probability/lifetime)  (number/year)
   ------                       ----------------   -------------------        -----------    ----------------------  -------------

Machine Operators
-----------------
    Commercial                       16000.              22050.                  3.15           0.1238                 28.29
    Industrial                         700.              28800.                  4.11           0.1585                  1.58
    Coin-Op                          11000.               2640.                0.3771           0.0157                  2.47

Other Workers
-------------
    Commercial                      110000.               4900.                0.7000           0.0289                 45.46
    Industrial                       20000.               6400.                0.9143           0.0376                 10.75
    Coin-Op                          22000.               2640.                0.3771           0.0157                  4.93

Service Users
-------------
    Commercial Dry Clean          50000000.                2.45              0.000350        1.466E-05                 10.47
    Coin-Op Dry Clean             25000000.                5.00              0.000714        2.998E-05                 10.71
    Coin-Op Laundry               37000000.               16.72              0.002389         0.000100                 52.96

Urban Residents
---------------
     25 -  200 *                   3700000.                1.68              0.000240        1.007E-05                0.5324
    200 -  500 *                  20000000.              0.2880             4.114E-05        1.726E-06                0.4930
    500 - 1000 *                  71000000.              0.0960             1.371E-05        5.752E-07                0.5834
                                                                                                                -------------
                                                                                                 Total              169.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    167.83
```

```
                         OPTION 12

Scaling: SURFACE_AREA    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =       0.001675
Option cost (millions of dollars) = -1.40  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime        Expected
  Type of                   Number in            Average Annual Exposure            Incidence          Annual Cases
  Person                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
  ------                 ----------------  -------------------    -----------   ---------------------   ------------

Machine Operators
-----------------
    Commercial                16000.            22050.                3.15             0.0165               3.77
    Industrial                  700.            28800.                4.11             0.0280               0.2796
    Coin-Up                   11000.             2640.              0,3771             0,000238             0,0374

Other Workers
-------------
    Commercial               110000.             4900.              0,7000             0,000821             1,29
    Industrial                20000.             6400.              0,9143             0,001400             0,3999
    Coin-Up                   22000.             2640.              0,3771             0,000238             0,0749

Service Users
-------------
    Commercial Dry Clean   50000000.              2,45              0.000350           2.052E-10            0,000147
    Coin-Up Dry Clean      25000000.              5,00              0,000714           8,548E-10            0,000305
    Coin-Up Laundry        37000000.             16,72              0,002389           9,559E-09            0,005053

Urban Residents
---------------
     25 -  200 *            3700000.              1,68              0,000240           9,651E-11            5,101E-06
    200 -  500 *           20000000.            0,2880              4.114E-05          2,836E-12            8,103E-07
    500 - 1000 *           71000000.            0,0960              1,371E-05          3,151E-13            3,196E-07
                                                                                                        -------------
                                                                                    Total                 5,86
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      4,46
```

```
                    OPTION 12

Scaling:  SURFACE_AREA    Species:     RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43,3 mg/kg/day which implies lambda =       0,001186
Option cost (millions of dollars) = -1,40  Cost per cancer case (millions of dollars) =  1,00

                                                                               Expected Lifetime      Expected
      Type of                   Number in            Average Annual Exposure       Incidence        Annual Cases
      Person                U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
      ------                ----------------  -------------------    -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                     16000.            22050.             3,15          0,003728            0,8521
    Industrial                       700.            28800.             4,11          0,004866            0,0487
    Coin-Op                        11000.             2640.           0,3771          0,000447            0,0702

Other Workers
-------------
    Commercial                    110000.             4900.           0,7000          0,000830              1,30
    Industrial                     20000.             6400.           0,9143          0,001083            0,3095
    Coin-Op                        22000.             2640.           0,3771          0,000447            0,1405

Service Users
-------------
    Commercial Dry Clean        50000000.              2,45         0,000350          4,150E-07           0,2964
    Coin-Op Dry Clean           25000000.              5,00         0,000714          8,469E-07           0,3025
    Coin-Op Laundry             37000000.             16.72         0,002389          2,832E-06             1,50

Urban Residents
---------------
      25 -  200 *                3700000.              1,68         0,000240          2,845E-07           0,0150
     200 -  500 *               20000000.            0,2880        4,114E-05          4,878E-08           0,0139
     500 - 1000 *               71000000.            0,0960        1,371E-05          1,626E-08           0,0165
                                                                                                       -------------
                                                                                         Total              4,87
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      3,47
```

```
                    OPTION 12

Scaling:  SURFACE_AREA    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) = -1.40  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime        Expected
   Type of                      Number in              Average Annual Exposure        Incidence           Annual Cases
   Person                    U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                    ----------------  --------------------     -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                   16000.             22050.                  3.15           0.000272            0.0621
    Industrial                     700.             28800.                  4.11           0.000464            0.004638
    Coin-Op                      11000.              2640.                  0.3771         3.898E-06           0.000613

Other Workers
-------------
    Commercial                  110000.              4900.                  0.7000         1.341E-05           0.0211
    Industrial                   20000.              6400.                  0.9143         2.289E-05           0.006539
    Coin-Op                      22000.              2640.                  0.3771         3.898E-06           0.001225

Service Users
-------------
    Commercial Dry Clean      50000000.              2.45                   0.000350       3.357E-12           2.398E-06
    Coin-Op Dry Clean         25000000.              5.00                   0.000714       1.398E-11           4.994E-06
    Coin-Op Laundry           37000000.             16.72                   0.002389       1.564E-10           8.264E-05

Urban Residents
---------------
     25 -  200 *               3700000.              1.68                   0.000240       1.579E-12           8.344E-08
    200 -  500 *              20000000.              0.2880                 4.114E-05      4.639E-14           1.325E-08
    500 - 1000 *              71000000.              0.0960                 1.371E-05      5.154E-15           5.226E-09
                                                                                                          -------------
                                                                                            Total              0.0963
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -1.30
```

```
                    OPTION 12

Scaling:  BODY_WEIGHT    Species: MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of  332,0 mg/kg/day which implies lambda =       0,003162
Option cost (millions of dollars) = -1,40  Cost per cancer case (millions of dollars) =  1,00

  Type of                         Number in          Average Annual Exposure          Expected Lifetime       Expected
  Person                       U. S. Population  (micro gms/cubic m)   (mg/kg/day)        Incidence          Annual Cases
  ------                       ----------------  -------------------   -----------  (probability/lifetime)  (number/year)
                                                                                     ----------------------  -------------
Machine Operators
-----------------
    Commercial                      16000.            22050.              3,15          0,009911               2,27
    Industrial                        700.            28800.              4,11            0,0129             0,1293
    Coin-Op                         11000.             2640.            0,3771          0,001192             0,1873

Other Workers
-------------
    Commercial                     110000.             4900.            0,7000          0,002211               3,47
    Industrial                      20000.             6400.            0,9143          0,002887             0,8248
    Coin-Op                         22000.             2640.            0,3771          0,001192             0,3746

Service Users
-------------
    Commercial Dry Clean         50000000.              2,45          0,000350         1,107E-06             0,7905
    Coin-Up Dry Clean            25000000.              5,00          0,000714         2,259E-06             0,8067
    Coin-Up Laundry              37000000.             16,72          0,002389         7,553E-06               3,99

Urban Residents
---------------
     25 -  200 *                  3700000.              1,68          0,000240         7,589E-07             0,0401
    200 -  500 *                 20000000.            0,2080         4,114E-05         1,301E-07             0,0372
    500 - 1000 *                 71000000.            0,0960         1,371E-05         4,337E-08             0,0440
                                                                                                        -------------
* Distance from dry cleaner in meters                                                        Total             12,97

Total cost of option and expected cancer (millions of dollars) =     11,57
```

```
                         OPTION 12

Scaling:  BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) = -1.40  Cost per cancer case (millions of dollars) =  1.00

                                                                                     Expected Lifetime       Expected
    Type of                        Number in           Average Annual Exposure          Incidence          Annual Cases
    Person                      U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
    ------                      ----------------  ------------------    -----------  ---------------------  ------------

Machine Operators
-----------------
    Commercial                       16000.             22050.              3.15          9.447E-05            0.0216
    Industrial                         700.             28800.              4.11          0.000161            0.001612
    Coin-Op                          11000.              2640.            0.3771          1.355E-06            0.000213

Other Workers
-------------
    Commercial                      110000.              4900.            0.7000          4.667E-06            0.007334
    Industrial                       20000.              6400.            0.9143          7.962E-06            0.002275
    Coin-Op                          22000.              2640.            0.3771          1.355E-06            0.000426

Service Users
-------------
    Commercial Dry Clean          50000000.              2.45           0.000350          1.167E-12          8.334E-07
    Coin-Op Dry Clean             25000000.              5.00           0.000714          4.859E-12          1.736E-06
    Coin-Op Laundry               37000000.             16.72           0.002389          5.434E-11          2.672E-05

Urban Residents
---------------
      25 -  200 *                  3700000.              1.68           0.000240          5.486E-13          2.900E-08
     200 -  500 *                 20000000.            0.2880          4.114E-05          1.612E-14          4.606E-09
     500 - 1000 *                 71000000.            0.0960          1.371E-05          1.791E-15          1.817E-09
                                                                                                         -------------
                                                                                           Total             0.0335
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -1.37
```

```
                     OPTION 12

Scaling:   BODY_WEIGHT    Species:    RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) = -1.40  Cost per cancer case (millions of dollars) =  1.00

                                                                                    Expected Lifetime        Expected
     Type of                     Number in           Average Annual Exposure            Incidence          Annual Cases
     Person                  U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                  ---------------   -------------------    -----------   ---------------------  ------------

Machine Operators
-----------------
     Commercial                   16000.             22050.                 3.15           0.000638            0.1459
     Industrial                     700.             28800.                 4.11           0.000834          0.008338
     Coin-Op                      11000.              2640.               0.3771          7.647E-05            0.0120

Other Workers
-------------
     Commercial                  110000.              4900.               0.7000           0.000142            0.2230
     Industrial                   20000.              6400.               0.9143           0.000185            0.0530
     Coin-Up                      22000.              2640.               0.3771          7.647E-05            0.0240

Service Users
-------------
     Commercial Dry Clean      50000000.               2.45             0.000350          7.096E-08            0.0507
     Coin-Op Dry Clean         25000000.               5.00             0.000714          1.448E-07            0.0517
     Coin-Up Laundry           37000000.              16.72             0.002389          4.843E-07            0.2560

Urban Residents
---------------
     25 -  200 *                3700000.               1.68             0.000240          4.866E-08          0.002572
     200 -  500 *              20000000.             0.2880            4.114E-05          8.341E-09          0.002383
     500 - 1000 *              71000000.             0.0960            1.371E-05          2.780E-09          0.002820
                                                                                                         -------------
                                                                                      Total                0.8324
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -0.57
```

OPTION 12

```
Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) = -1.40  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime       Expected
     Type of                 Number in            Average Annual Exposure             Incidence          Annual Cases
     Person               U. S. Population   (micro gms/cubic m)      (mg/kg/day)    (probability/lifetime)  (number/year)
     ------               ----------------   -------------------      -----------   ----------------------  ------------

Machine Operators
-----------------
     Commercial                16000.              22050.                3.15           7.951E-06            0.001817
     Industrial                  700.              28800.                4.11           1.359E-05            0.000136
     Coin-Op                   11000.               2640.                0.3771         1.140E-07            1.791E-05

Other Workers
-------------
     Commercial               110000.               4900.                0.7000         3.927E-07            0.000617
     Industrial                20000.               6400.                0.9143         6.699E-07            0.000191
     Coin-Op                   22000.               2640.                0.3771         1.140E-07            3.582E-05

Service Users
-------------
     Commercial Dry Clean   50000000.                2.45                0.000350       9.816E-14            7.012E-08
     Coin-Op Dry Clean      25000000.                5.00                0.000714       4.088E-13            1.460E-07
     Coin-Op Laundry        37000000.               16.72                0.002389       4.572E-12            2.417E-06

Urban Residents
---------------
      25 -  200 *            3700000.                1.68                0.000240       4.616E-14            2.440E-09
     200 -  500 *           20000000.                0.2080              4.114E-05      1.356E-15            3.676E-10
     500 - 1000 *           71000000.                0.0960              1.371E-05      1.507E-16            1.529E-10
                                                                                                          -------------
                                                                                          Total            0.002818

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -1.40
```

```
                    OPTION 13

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =         0.0419
Option cost (millions of dollars) = -5.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime       Expected
     Type of                      Number in           Average Annual Exposure       Incidence         Annual Cases
     Person                    U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                    ----------------  -------------------    -----------  ----------------------  -------------

Machine Operators
-----------------
    Commercial                      16000.             22050.              3,15            0.1238              28,29
    Industrial                        700.             28800.              4,11            0.1585               1,58
    Coin-Op                         11000.              2640.            0,3771            0.0157               2,47

Other Workers
-------------
    Commercial                     110000.              4900.            0,7000            0.0289              45,46
    Industrial                      20000.              6400.            0,9143            0.0376              10,75
    Coin-Op                         22000.              2640.            0,3771            0.0157               4,93

Service Users
-------------
    Commercial Dry Clean         50000000.              2,45           0,000350         1,466E-05            10,47
    Coin-Op Dry Clean            25000000.              5,00           0,000714         2,998E-05            10,71
    Coin-Op Laundry              37000000.              1,67           0,000239         1,001E-05             5,29

Urban Residents
---------------
     25 -  200 *                  3700000.              1,68           0,000240         1,007E-05            0.5324
    200 -  500 *                 20000000.            0,2880          4,114E-05         1,726E-06            0.4930
    500 - 1000 *                 71000000.            0,0960          1,371E-05         5,752E-07            0.5834
                                                                                                        -------------
                                                                                     Total                  122.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    116,36
```

```
                UPTION 13

Scaling:  SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =       0.001186
Option cost (millions of dollars) = -5.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                        Expected Lifetime        Expected
     Type of                       Number in            Average Annual Exposure            Incidence           Annual Cases
     Person                     U. S. Population   (micro gms/cubic m)       (mg/kg/day)    (probability/lifetime)   (number/year)
     ------                     ----------------   --------------------      -----------    ----------------------   ------------

Machine Operators
-----------------
    Commercial                       16000.             22050.                   3.15            0.003728              0.8521
    Industrial                         700.             28800.                   4.11            0.004866              0.0487
    Coin-Op                          11000.              2640.                 0.3771            0.000447              0.0702

Other Workers
-------------
    Commercial                      110000.              4900.                 0.7000            0.000830                1.30
    Industrial                       20000.              6400.                 0.9143            0.001083              0.3095
    Coin-Op                          22000.              2640.                 0.3771            0.000447              0.1405

Service Users
-------------
    Commercial Dry Clean          50000000.              2.45                0.000350            4.150E-07             0.2964
    Coin-Op Dry Clean             25000000.              5.00                0.000714            8.469E-07             0.3025
    Coin-Op Laundry               37000000.              1.67                0.000239            2.832E-07             0.1497

Urban Residents
---------------
     25 -  200 *                   3700000.              1.68                0.000240            2.845E-07             0.0150
    200 -  500 *                  20000000.            0.2880               4.114E-05            4.878E-08             0.0139
    500 - 1000 *                  71000000.            0.0960               1.371E-05            1.626E-08             0.0165
                                                                                                                  -------------
                                                                                                   Total               3.52
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -1.68
```

```
                         OPTION 13

Scaling: SURFACE_AREA    Species:    RAT    Model: QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) = -5.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
   Type of                      Number in            Average Annual Exposure         Incidence         Annual Cases
   Person                    U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
   ------                    ----------------  -------------------     -----------  ----------------------  ------------

Machine Operators
-----------------
    Commercial                   16000.              22050.              3.15         0.000272             0.0621
    Industrial                     700.              28800.              4.11         0.000464             0.004638
    Coin-Op                      11000.               2640.              0.3771       3.898E-06            0.000613

Other Workers
-------------
    Commercial                  110000.               4900.              0.7000       1.341E-05            0.0211
    Industrial                   20000.               6400.              0.9143       2.289E-05            0.006539
    Coin-Op                      22000.               2640.              0.3771       3.898E-06            0.001225

Service Users
-------------
    Commercial Dry Clean      50000000.                2.45              0.000350     3.357E-12            2.398E-06
    Coin-Op Dry Clean         25000000.                5.00              0.000714     1.398E-11            4.994E-06
    Coin-Op Laundry           37000000.                1.67              0.000239     1.564E-12            6.264E-07

Urban Residents
---------------
      25 -  200 *              3700000.                1.68              0.000240     1.579E-12            8.344E-08
     200 -  500 *             20000000.              0.2880              4.114E-05    4.639E-14            1.325E-08
     500 - 1000 *             71000000.              0.0960              1.371E-05    5.154E-15            5.228E-09
                                                                                                         -------------
                                                                                     Total                 0.0962
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -5.10
```

```
                    OPTION 13

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) = -5.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime        Expected
    Type of                  Number in             Average Annual Exposure          Incidence          Annual Cases
    Person                U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
    Commercial                  16000.            22050.              3.15          0.009911                  2.27
    Industrial                    700.            28800.              4.11            0.0129                0.1293
    Coin-Op                     11000.             2640.            0.3771          0.001192                0.1873

Other Workers
-------------
    Commercial                 110000.             4900.            0.7000          0.002211                  3.47
    Industrial                  20000.             6400.            0.9143          0.002887                0.8248
    Coin-Op                     22000.             2640.            0.3771          0.001192                0.3746

Service Users
-------------
    Commercial Dry Clean     50000000.             2.45           0.000350         1.107E-06               0.7905
    Coin-Op Dry Clean        25000000.             5.00           0.000714         2.259E-06               0.8067
    Coin-Op Laundry          37000000.             1.67           0.000239         7.553E-07               0.3992

Urban Residents
---------------
      25 -  200 *             3700000.             1.68           0.000240         7.589E-07               0.0401
     200 -  500 *            20000000.           0.2880          4.114E-05         1.301E-07               0.0372
     500 - 1000 *            71000000.           0.0960          1.371E-05         4.337E-08               0.0440
                                                                                                       -------------
                                                                                     Total                   9.37
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      4.17
```

```
                      OPTION 13

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =      9.524E-06
Option cost (millions of dollars) = -5.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                  Expected Lifetime        Expected
     Type of                    Number in             Average Annual Exposure         Incidence          Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------    -----------   ---------------------   ------------

Machine Operators
-----------------
     Commercial                   16000.              22050.               3.15          9.447E-05           0.0216
     Industrial                     700.              28800.               4.11          0.000161          0.001612
     Coin-Up                      11000.               2640.             0.3771          1.355E-06         0.000213

Other Workers
-------------
     Commercial                  110000.               4900.             0.7000          4.667E-06         0.007334
     Industrial                   20000.               6400.             0.9143          7.962E-06         0.002275
     Coin-Op                      22000.               2640.             0.3771          1.355E-06         0.000426

Service Users
-------------
     Commercial Dry Clean     50000000.                2.45            0.000350          1.167E-12        8.334E-07
     Coin-Up Dry Clean        25000000.                5.00            0.000714          4.859E-12        1.736E-06
     Coin-Op Laundry          37000000.                1.67            0.000239          5.434E-13        2.872E-07

Urban Residents
---------------
       25 -  200 *             3700000.                1.68            0.000240          5.486E-13        2.900E-08
      200 -  500 *            20000000.              0.2080           4.114E-05          1.612E-14        4.606E-09
      500 - 1000 *            71000000.              0.0960           1.371E-05          1.791E-15        1.817E-09
                                                                                                        -------------
                                                                                          Total           0.0335
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -5.17
```

```
                      OPTION 13

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) = -5.20  Cost per cancer case (millions of dollars) =  1.00

                                                                                      Expected Lifetime       Expected
     Type of                           Number in            Average Annual Exposure       Incidence         Annual Cases
     Person                       U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime) (number/year)
     ------                       ----------------  -------------------    -----------  ---------------------- -------------

Machine Operators
-----------------
    Commercial                        16000.             22050.              3.15           0.000638            0.1459
    Industrial                          700.             28800.              4.11           0.000834          0.008336
    Coin-Up                           11000.              2640.            0.3771          7.647E-05            0.0120

Other Workers
-------------
    Commercial                       110000.              4900.            0.7000           0.000142            0.2230
    Industrial                        20000.              6400.            0.9143           0.000185            0.0530
    Coin-Up                           22000.              2640.            0.3771          7.647E-05            0.0240

Service Users
-------------
    Commercial Dry Clean           50000000.              2.45           0.000350          7.096E-08            0.0507
    Coin-Up Dry Clean              25000000.              5.00           0.000714          1.448E-07            0.0517
    Coin-Up Laundry                37000000.              1.67           0.000239          4.843E-08            0.0256

Urban Residents
---------------
      25 -  200 *                   3700000.              1.68           0.000240          4.866E-08          0.002572
     200 -  500 *                  20000000.            0.2880          4.114E-05          8.341E-09          0.002383
     500 - 1000 *                  71000000.            0.0960          1.371E-05          2.760E-09          0.002820
                                                                                                         -------------
                                                                                              Total           0.6021
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -4.60
```

```
                    UPTION 13

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253,0 mg/kg/day which implies lambda =      8,013E-07
Option cost (millions of dollars) = -5,20  Cost per cancer case (millions of dollars) =  1,00

                                                                              Expected Lifetime       Expected
     Type of                  Number in           Average Annual Exposure         Incidence         Annual Cases
     Person                U, S, Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                ----------------  -------------------    -----------  ----------------------  -------------

Machine Operators
-----------------
     Commercial                 16000,            22050,               3,15          7,951E-06           0,001817
     Industrial                   700,            28800,               4,11          1,359E-05           0,000136
     Coin-Op                    11000,             2640,             0,3771          1,140E-07          1,791E-05

Other workers
-------------
     Commercial                110000,             4900,             0,7000          3,927E-07           0,000617
     Industrial                 20000,             6400,             0,9143          6,699E-07           0,000191
     Coin-Op                    22000,             2640,             0,3771          1,140E-07          3,582E-05

Service Users
-------------
     Commercial Dry Clean    50000000,             2,45           0,000350          9,816E-14          7,012E-08
     Coin-Op Dry Clean       25000000,             5,00           0,000714          4,088E-13          1,460E-07
     Coin-Op Laundry         37000000,             1,67           0,000239          4,572E-14          2,417E-08

Urban Residents
---------------
      25 -  200 *             3700000,             1,68           0,000240          4,616E-14          2,440E-09
     200 -  500 *            20000000,           0,2880          4,114E-05          1,356E-15          3,876E-10
     500 - 1000 *            71000000,           0,0960          1,371E-05          1,507E-16          1,529E-10
                                                                                                    -------------
                                                                                    Total           0,002816
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     -5,20
```

```
                    OPTION 14

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =         0.0419
Option cost (millions of dollars) =  0.60  Cost per cancer case (millions of dollars) =  1.00

                                                                                   Expected Lifetime       Expected
    Type of                 Number in           Average Annual Exposure                Incidence          Annual Cases
    Person               U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
    ------               ----------------  -------------------    -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                16000.             14400.              2.06              0.0827               18.89
     Industrial                  700.             28600.              4.11              0.1585                1.58
     Coin-Op                   11000.              3300.            0.4714              0.0196                3.08

Other Workers
-------------
     Commercial               110000.              4900.            0.7000              0.0289               45.46
     Industrial                20000.              6400.            0.9143              0.0376               10.75
     Coin-Op                   22000.              3300.            0.4714              0.0196                6.15

Service Users
-------------
     Commercial Dry Clean   50000000.              2.45           0.000350           1.466E-05              10.47
     Coin-Op Dry Clean      25000000.              5.90           0.000843           3.535E-05              12.62
     Coin-Op Laundry        37000000.              2.09           0.000299           1.252E-05               6.62

Urban Residents
---------------
       25 -  200 *           3700000.              1.82           0.000260           1.091E-05              0.5765
      200 -  500 *          20000000.            0.3120          4.457E-05           1.869E-06              0.5341
      500 - 1000 *          71000000.            0.1040          1.486E-05           6.231E-07              0.6320
                                                                                                        -------------
                                                                                          Total             117.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =    117.97
```

```
                              OPTION 14

Scaling:  SURFACE_AREA    Species:  MOUSE    Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =      0.001675
Option cost (millions of dollars) =  0.60  Cost per cancer case (millions of dollars) =  1.00

    Type of                                                                     Expected Lifetime      Expected
    Person                     Number in          Average Annual Exposure            Incidence         Annual Cases
    ------                 U. S. Population  (micro gms/cubic m)    (mg/kg/day)  (probability/lifetime) (number/year)
                           ----------------  -------------------    -----------  ---------------------- -------------

Machine Operators
-----------------
    Commercial                    16000.           14400.              2.06          0.007065             1.61
    Industrial                      700.           28800.              4.11            0.0280           0.2796
    Coin-Op                       11000.            3300.            0.4714          0.000372           0.0565

Other Workers
-------------
    Commercial                   110000.            4900.            0.7000          0.000821             1.29
    Industrial                    20000.            6400.            0.9143          0.001400           0.3999
    Coin-Op                       22000.            3300.            0.4714          0.000372           0.1170

Service Users
-------------
    Commercial Dry Clean       50000000.             2.45          0.000350         2.052E-10         0.000147
    Coin-Op Dry Clean          25000000.             5.90          0.000843         1.190E-09         0.000425
    Coin-Op Laundry            37000000.             2.09          0.000299         1.494E-10        7.895E-05

Urban Residents
---------------
     25 -  200 *                3700000.             1.82          0.000260         1.133E-10        5.987E-06
    200 -  500 *               20000000.           0.3120         4.457E-05         3.328E-12        9.510E-07
    500 - 1000 *               71000000.           0.1040         1.486E-05         3.698E-13        3.751E-07
                                                                                                 -------------
* Distance from dry cleaner in meters                                                   Total           3.76

Total cost of option and expected cancer (millions of dollars) =      4.36
```

```
                          OPTION 14

Scaling: SURFACE_AREA    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      0.001186
Option cost (millions of dollars) =  0.60  Cost per cancer case (millions of dollars) =  1.00
                                                                                Expected Lifetime       Expected
     Type of                    Number in          Average Annual Exposure           Incidence          Annual Cases
     Person                  U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                  ----------------  -------------------     -----------   ---------------------  ------------

Machine Operators
-----------------
     Commercial                  16000.              14400.               2.06         0.002436               0.5568
     Industrial                    700.              28800.               4.11         0.004866               0.0487
     Coin-Op                     11000.               3300.             0.4714         0.000559               0.0678

Other Workers
-------------
     Commercial                 110000.               4900.             0.7000         0.000830                 1.30
     Industrial                  20000.               6400.             0.9143         0.001083               0.3095
     Coin-Op                     22000.               3300.             0.4714         0.000559               0.1756

Service Users
-------------
     Commercial Dry Clean     50000000.               2.45            0.000350        4.150E-07               0.2964
     Coin-Op Dry Clean        25000000.               5.90            0.000843        9.993E-07               0.3569
     Coin-Op Laundry          37000000.               2.09            0.000299        3.540E-07               0.1871

Urban Residents
---------------
       25 -  200 *             3700000.               1.82            0.000260        3.083E-07               0.0163
      200 -  500 *            20000000.             0.3120           4.457E-05        5.284E-08               0.0151
      500 - 1000 *            71000000.             0.1040           1.486E-05        1.761E-08               0.0179
                                                                                                        ------------
                                                                                      Total                     3.37
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      3.97
```

```
                 OPTION 14

Scaling:  SURFACE_AREA    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of   43.3 mg/kg/day which implies lambda =      2.740E-05
Option cost (millions of dollars) =  0.60  Cost per cancer case (millions of dollars) =  1.00

                                                                                Expected Lifetime       Expected
    Type of                  Number in            Average Annual Exposure           Incidence          Annual Cases
    Person               U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
    ------               ----------------  -------------------     -----------   ---------------------  ------------

Machine Operators
-----------------
    Commercial                16000.            14400.                2.06            0.000116              0.0265
    Industrial                  700.            28800.                4.11            0.000464              0.004638
    Coin-Op                   11000.             3300.              0.4714           6.091E-06              0.000957

Other Workers
-------------
    Commercial               110000.             4900.              0.7000           1.341E-05              0.0211
    Industrial                20000.             6400.              0.9143           2.289E-05              0.006539
    Coin-Up                   22000.             3300.              0.4714           6.091E-06              0.001914

Service Users
-------------
    Commercial Dry Clean   50000000.             2.45             0.000350           3.357E-12             2.398E-06
    Coin-Op Dry Clean      25000000.             5.90             0.000843           1.947E-11             6.953E-06
    Coin-Op Laundry        37000000.             2.09             0.000299           2.443E-12             1.291E-06

Urban Residents
---------------
      25 -  200 *           3700000.             1.82             0.000260           1.853E-12             9.792E-08
     200 -  500 *          20000000.           0.3120            4.457E-05           5.444E-14             1.555E-08
     500 - 1000 *          71000000.           0.1040            1.486E-05           6.049E-15             6.136E-09
                                                                                                       -------------
* Distance from dry cleaner in meters                                                   Total              0.0616

Total cost of option and expected cancer (millions of dollars) =      0.66
```

```
                    OPTION 14

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) =  0.60  Cost per cancer case (millions of dollars) =  1.00

                                                                                         Expected Lifetime        Expected
     Type of                        Number in              Average Annual Exposure           Incidence           Annual Cases
     Person                      U. S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                      ----------------  -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                      16000.             14400.                  2.06          0.006484               1.48
     Industrial                        700.             28800.                  4.11            0.0129             0.1293
     Coin-Op                         11000.              3300.                0.4714          0.001490             0.2341

Other Workers
-------------
     Commercial                     110000.              4900.                0.7000          0.002211               3.47
     Industrial                      20000.              6400.                0.9143          0.002087             0.8248
     Coin-Op                         22000.              3300.                0.4714          0.001490             0.4662

Service Users
-------------
     Commercial Dry Clean         50000000.              2.45               0.000350         1.107E-06             0.7905
     Coin-Op Dry Clean            25000000.              5.90               0.000843         2.665E-06             0.9519
     Coin-Op Laundry              37000000.              2.09               0.000299         9.441E-07             0.4990

Urban Residents
---------------
       25 -  200 *                 3700000.              1.82               0.000260         8.221E-07             0.0435
      200 -  500 *                20000000.            0.3120              4.457E-05         1.409E-07             0.0403
      500 - 1000 *                71000000.            0.1040              1.486E-05         4.698E-08             0.0477
                                                                                                               -------------
                                                                                               Total                8.99
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      9.59
```

```
                                   OPTION 14

Scaling:   BODY_WEIGHT    Species: MOUSE    Model: QUADRATIC
Response of 65 percent corresponds to dose in man of  332,0 mg/kg/day which implies lambda =      9,524E-06
Option cost (millions of dollars) =  0,60  Cost per cancer case (millions of dollars) =  1,00

                                                                                   Expected Lifetime       Expected
      Type of                        Number in          Average Annual Exposure        Incidence          Annual Cases
      Person                      U. S. Population  (micro gms/cubic m)    (mg/kg/day)   (probability/lifetime)  (number/year)
      ------                      ----------------  -------------------    -----------   ---------------------  ------------

Machine Operators
-----------------
    Commercial                          16000.            14400.              2,06          4,029E-05            0,009210
    Industrial                            700.            28800.              4,11          0,000161             0,001612
    Coin-Op                             11000.             3300.            0,4714          2,117E-06            0,000333

Other Workers
-------------
    Commercial                         110000.             4900.            0,7000          4,667E-06            0,007334
    Industrial                          20000.             6400.            0,9143          7,962E-06            0,002275
    Coin-Op                             22000.             3300.            0,4714          2,117E-06            0,000665

Service Users
-------------
    Commercial Dry Clean            50000000.              2,45           0,000350          1,167E-12            8,334E-07
    Coin-Op Dry Clean               25000000.              5,90           0,000843          6,766E-12            2,417E-06
    Coin-Op Laundry                 37000000.              2,09           0,000299          8,491E-13            4,488E-07

Urban Residents
---------------
     25 -  200 *                     3700000.              1,82           0,000260          6,439E-13            3,403E-08
    200 -  500 *                    20000000.            0,3120          4,457E-05          1,892E-14            5,406E-09
    500 - 1000 *                    71000000.            0,1040          1,486E-05          2,102E-15            2,132E-09
                                                                                                            -------------
                                                                                         Total               0,0214
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      0,62
```

```
                        OPTION 14

Scaling:  BODY_WEIGHT   Species:   RAT   Model:    LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =       0.000203
Option cost (millions of dollars) =  0.60  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime       Expected
   Type of                     Number in             Average Annual Exposure         Incidence         Annual Cases
   Person                  U. S. Population   (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
   ------                  ----------------   -------------------     -----------   ---------------------- -------------

Machine Operators
-----------------
     Commercial                   16000.             14400.              2.06            0.000417           0.0953
     Industrial                     700.             28800.              4.11            0.000834         0.008338
     Coin-Op                      11000.              3300.            0.4714           9.555E-05           0.0150

Other Workers
-------------
     Commercial                  110000.              4900.            0.7000            0.000142           0.2230
     Industrial                   20000.              6400.            0.9143            0.000185           0.0530
     Coin-Op                      22000.              3300.            0.4714           9.555E-05           0.0300

Service Users
-------------
     Commercial Dry Clean      50000000.               2.45          0.000350           7.096E-08           0.0507
     Coin-Op Dry Clean         25000000.               5.90          0.000843           1.709E-07           0.0610
     Coin-Op Laundry           37000000.               2.09          0.000299           6.053E-08           0.0320

Urban Residents
---------------
       25 -  200 *              3700000.               1.82          0.000260           5.271E-08         0.002786
      200 -  500 *             20000000.             0.3120         4.457E-05           9.036E-09         0.002582
      500 - 1000 *             71000000.             0.1040         1.486E-05           3.012E-09         0.003055
                                                                                                      -------------
                                                                                          Total           0.5768
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      1.18
```

```
                        OPTION 14

Scaling:  BODY_WEIGHT   Species:   RAT   Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =      8.013E-07
Option cost (millions of dollars) =  0.60  Cost per cancer case (millions of dollars) =  1.00

     Type of                                                                                  Expected Lifetime       Expected
     Person                 Number in                   Average Annual Exposure                  Incidence          Annual Cases
     ------              U. S. Population   (micro gms/cubic m)      (mg/kg/day)        (probability/lifetime)   (number/year)
                         ----------------   -------------------     -----------         ----------------------   -------------
Machine Operators
-----------------
     Commercial                16000.              14400.               2.06                3.391E-06              0.000775
     Industrial                  700.              28800.               4.11                1.359E-05              0.000136
     Coin-Op                   11000.               3300.             0.4714                1.781E-07             2.799E-05

Other Workers
-------------
     Commercial               110000.               4900.             0.7000                3.927E-07              0.000617
     Industrial                20000.               6400.             0.9143                6.699E-07              0.000191
     Coin-Op                   22000.               3300.             0.4714                1.781E-07             5.597E-05

Service Users
-------------
     Commercial Dry Clean   50000000.                2.45           0.000350                9.816E-14             7.012E-08
     Coin-Op Dry Clean      25000000.                5.90           0.000843                5.693E-13             2.033E-07
     Coin-Op Laundry        37000000.                2.09           0.000299                7.144E-14             3.776E-08

Urban Residents
---------------
        25 -  200 *          3700000.                1.82           0.000260                5.417E-14             2.863E-09
       200 -  500 *         20000000.              0.3120          4.457E-05                1.592E-15             4.548E-10
       500 - 1000 *         71000000.              0.1040          1.486E-05                1.769E-16             1.794E-10
                                                                                                                --------------
* Distance from dry cleaner in meters                                                         Total              0.001804

Total cost of option and expected cancer (millions of dollars) =      0.60
```

```
                         OPTION 15

Scaling: SURFACE_AREA    Species: MOUSE    Model:     LINEAR
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =         0.0419
Option cost (millions of dollars) =  3.50  Cost per cancer case (millions of dollars) =  1.00

                                                                                          Expected Lifetime         Expected
    Type of                           Number in            Average Annual Exposure            Incidence           Annual Cases
    Person                         U. S. Population   (micro gms/cubic m)       (mg/kg/day)    (probability/lifetime)   (number/year)
    ------                         ----------------   -------------------       -----------    ----------------------   -------------

Machine Operators
-----------------
    Commercial                         16000.              14400.                  2.06              0.0827                 18.89
    Industrial                           700.              28800.                  4.11              0.1585                  1.58
    Coin-Op                            11000.               2640.                0.3771              0.0157                  2.47

Other Workers
-------------
    Commercial                        110000.               4900.                0.7000              0.0289                 45.46
    Industrial                         20000.               6400.                0.9143              0.0376                 10.75
    Coin-Op                            22000.               2640.                0.3771              0.0157                  4.93

Service Users
-------------
    Commercial Dry Clean            50000000.               2.45               0.000350           1.466E-05                 10.47
    Coin-Op Dry Clean               25000000.               5.00               0.000714           2.998E-05                 10.71
    Coin-Op Laundry                 37000000.               1.67               0.000239           1.001E-05                  5.29

Urban Residents
---------------
     25 -  200 *                     3700000.               1.68               0.000240           1.007E-05                0.5324
    200 -  500 *                    20000000.             0.2880              4.114E-05           1.726E-06                0.4930
    500 - 1000 *                    71000000.             0.0960              1.371E-05           5.752E-07                0.5834
                                                                                                                    -------------
                                                                                                   Total                  112.
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =     115.67
```

```
                 OPTION 15

Scaling:  SURFACE_AREA    Species:  MOUSE     Model:  QUADRATIC
Response of 65 percent corresponds to dose in man of   25.0 mg/kg/day which implies lambda =        0.001675
Option cost (millions of dollars) =  3.50  Cost per cancer case (millions of dollars) =  1.00

                                                                               Expected Lifetime        Expected
     Type of                   Number in            Average Annual Exposure        Incidence          Annual Cases
     Person                 U. S. Population  (micro gms/cubic m)     (mg/kg/day)  (probability/lifetime)  (number/year)
     ------                 ----------------  -------------------     -----------  ---------------------  -------------

Machine Operators
-----------------
     Commercial                  16000.             14400.              2.06          0.007065              1.61
     Industrial                    700.             28800.              4.11            0.0280            0.2796
     Coin-Op                     11000.              2640.            0.3771          0.000238            0.0374

Other Workers
-------------
     Commercial                 110000.              4900.            0.7000          0.000821              1.29
     Industrial                  20000.              6400.            0.9143          0.001400            0.3999
     Coin-Op                     22000.              2640.            0.3771          0.000238            0.0749

Service Users
-------------
     Commercial Dry Clean     50000000.              2.45           0.000350         2.052E-10          0.000147
     Coin-Op Dry Clean        25000000.              5.00           0.000714         8.548E-10          0.000305
     Coin-Op Laundry          37000000.              1.67           0.000239         9.559E-11         5.053E-05

Urban Residents
---------------
       25 -  200 *             3700000.              1.68           0.000240         9.651E-11         5.101E-06
      200 -  500 *            20000000.            0.2880          4.114E-05         2.836E-12         8.103E-07
      500 - 1000 *            71000000.            0.0960          1.371E-05         3.151E-13         3.196E-07
                                                                                                   -------------
* Distance from dry cleaner in meters                                                    Total              3.70

Total cost of option and expected cancer (millions of dollars) =      7.20
```

```
                           OPTION 15

Scaling: SURFACE_AREA    Species:    RAT    Model:    LINEAR
Response of  5 percent corresponds to dose in man of   43,3 mg/kg/day which implies lambda =       0,001186
Option cost (millions of dollars) =  3,50  Cost per cancer case (millions of dollars) =  1,00

                                                                                        Expected Lifetime          Expected
     Type of                     Number in           Average Annual Exposure               Incidence            Annual Cases
     Person                   U, S, Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                   ----------------  -------------------      -----------   ----------------------  -------------

Machine Operators
-----------------
     Commercial                    16000,             14400,                 2,06            0,002436               0,5568
     Industrial                      700,             28800,                 4,11            0,004866               0,0467
     Coin-Op                       11000,              2640,               0,3771            0,000447               0,0702

Other Workers
-------------
     Commercial                   110000,              4900,               0,7000            0,000830                 1,30
     Industrial                    20000,              6400,               0,9143            0,001083               0,3095
     Coin-Op                       22000,              2640,               0,3771            0,000447               0,1405

Service Users
-------------
     Commercial Dry Clean       50000000,              2,45              0,000350           4,150E-07               0,2964
     Coin-Op Dry Clean          25000000,              5,00              0,000714           8,469E-07               0,3025
     Coin-Op Laundry            37000000,              1,67              0,000239           2,832E-07               0,1497

Urban Residents
---------------
       25 -  200 *               3700000,              1,68              0,000240           2,845E-07               0,0150
      200 -  500 *              20000000,            0,2880             4,114E-05           4,878E-08               0,0139
      500 - 1000 *              71000000,            0,0960             1,371E-05           1,626E-08               0,0165
                                                                                                               -------------
                                                                                                 Total                  3,22

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      6,72
```

```
                    OPTION 15

Scaling: SURFACE_AREA    Species:    RAT    Model: QUADRATIC
Response of  5 percent corresponds to dose in man of   43,3 mg/kg/day which implies lambda =      2,740E-05
Option cost (millions of dollars) =  3,50  Cost per cancer case (millions of dollars) =  1,00

                                                                                    Expected Lifetime        Expected
     Type of                        Number in             Average Annual Exposure          Incidence          Annual Cases
     Person                     U, S. Population  (micro gms/cubic m)      (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                     ----------------  -------------------      -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                     16000,              14400,                 2,06            0.000116              0,0265
    Industrial                       700,              28800,                 4,11            0.000464            0,004638
    Coin-Op                        11000,               2640,               0,3771           3.898E-06            0,000613

Other Workers
-------------
    Commercial                    110000,               4900,               0,7000           1.341E-05              0,0211
    Industrial                     20000,               6400,               0,9143           2,289E-05            0,006539
    Coin-Up                        22000,               2640,               0,3771           3,896E-06            0,001225

Service Users
-------------
    Commercial Dry Clean        50000000,               2,45              0,000350           3,357E-12           2,398E-06
    Coin-Op Dry Clean           25000000,               5.00              0,000714           1,398E-11           4,994E-06
    Coin-Op Laundry             37000000,               1,67              0,000239           1,564E-12           8,264E-07

Urban Residents
---------------
     25 -  200 *                 3700000,               1,68              0,000240           1,579E-12           8,344E-08
    200 -  500 *                20000000,             0,2680             4.114E-05           4,639E-14           1.325E-08
    500 - 1000 *                71000000,             0,0960             1.371E-05           5,154E-15           5,228E-09
                                                                                                              -------------
                                                                                             Total               0,0606
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      3,56
```

```
                                  OPTION 15

Scaling:   BODY_WEIGHT    Species:  MOUSE    Model:    LINEAR
Response of 65 percent corresponds to dose in man of  332.0 mg/kg/day which implies lambda =       0.003162
Option cost (millions of dollars) =  3.50  Cost per cancer case (millions of dollars) =  1.00

     Type of                                                                    Expected Lifetime      Expected
     Person                  Number in          Average Annual Exposure            Incidence          Annual Cases
     ------              U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
                         ----------------  -------------------     -----------   ---------------------  ------------
Machine Operators
-----------------
    Commercial                16000.             14400.               2.06          0.006484               1.48
    Industrial                  700.             28800.               4.11            0.0129             0.1293
    Coin-Op                   11000.              2640.             0.3771          0.001192             0.1873

Other Workers
-------------
    Commercial               110000.              4900.             0.7000          0.002211               3.47
    Industrial                20000.              6400.             0.9143          0.002887             0.8248
    Coin-Op                   22000.              2640.             0.3771          0.001192             0.3746

Service Users
-------------
    Commercial Dry Clean   50000000.               2.45           0.000350         1.107E-06             0.7905
    Coin-Up Dry Clean      25000000.               5.00           0.000714         2.259E-06             0.8067
    Coin-Up Laundry        37000000.               1.67           0.000239         7.553E-07             0.3992

Urban Residents
---------------
     25 -  200 *            3700000.               1.68           0.000240         7.589E-07             0.0401
    200 -  500 *           20000000.             0.2880          4.114E-05         1.301E-07             0.0372
    500 - 1000 *           71000000.             0.0960          1.371E-05         4.337E-08             0.0440
                                                                                                    ------------
* Distance from dry cleaner in meters                                                Total                 8.59

Total cost of option and expected cancer (millions of dollars) =     12.09
```

OPTION 15

Scaling: BODY_WEIGHT Species: MOUSE Model: QUADRATIC
Response of 65 percent corresponds to dose in man of 332,0 mg/kg/day which implies lambda = 9,524E-06
Option cost (millions of dollars) = 3,50 Cost per cancer case (millions of dollars) = 1.00

Type of Person	Number in U. S. Population	Average Annual Exposure (micro gms/cubic m)	Average Annual Exposure (mg/kg/day)	Expected Lifetime Incidence (probability/lifetime)	Expected Annual Cases (number/year)
Machine Operators					
Commercial	16000.	14400.	2,06	4,029E-05	0,009210
Industrial	700.	28800.	4,11	0.000161	0,001612
Coin-Op	11000.	2640.	0,3771	1,355E-06	0,000213
Other Workers					
Commercial	110000.	4900.	0,7000	4,667E-06	0,007334
Industrial	20000.	6400.	0,9143	7,962E-06	0,002275
Coin-Op	22000.	2640.	0,3771	1,355E-06	0,000426
Service Users					
Commercial Dry Clean	50000000.	2,45	0,000350	1,167E-12	8,334E-07
Coin-Op Dry Clean	25000000.	5,00	0,000714	4,859E-12	1,736E-06
Coin-Op Laundry	37000000.	1,67	0,000239	5,434E-13	2,872E-07
Urban Residents					
25 - 200 *	3700000.	1,68	0,000240	5,486E-13	2,900E-08
200 - 500 *	20000000.	0,2880	4,114E-05	1,612E-14	4,606E-09
500 - 1000 *	71000000.	0,0960	1,371E-05	1,791E-15	1,817E-09
				Total	0,0211

* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) = 3,52

```
                        OPTION 15

Scaling:   BODY_WEIGHT    Species:    RAT    Model:     LINEAR
Response of  5 percent corresponds to dose in man of  253.0 mg/kg/day which implies lambda =        0.000203
Option cost (millions of dollars) =  3.50  Cost per cancer case (millions of dollars) =  1.00

                                                                                 Expected Lifetime        Expected
     Type of                  Number in           Average Annual Exposure           Incidence           Annual Cases
     Person                U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
     ------                ----------------  -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
     Commercial                  16000.             14400.               2.06           0.000417              0.0953
     Industrial                    700.             28600.               4.11           0.000834            0.008338
     Coin-Op                     11000.              2640.             0.3771          7.647E-05              0.0120

Other Workers
-------------
     Commercial                 110000.              4900.             0.7000           0.000142              0.2230
     Industrial                  20000.              6400.             0.9143           0.000185              0.0530
     Coin-Op                     22000.              2640.             0.3771          7.647E-05              0.0240

Service Users
-------------
     Commercial Dry Clean     50000000.               2.45           0.000350          7.096E-08              0.0507
     Coin-Op Dry Clean        25000000.               5.00           0.000714          1.448E-07              0.0517
     Coin-Op Laundry          37000000.               1.67           0.000239          4.843E-08              0.0256

Urban Residents
---------------
      25 -  200 *              3700000.               1.68           0.000240          4.866E-08            0.002572
     200 -  500 *             20000000.             0.2880          4.114E-05          8.341E-09            0.002383
     500 - 1000 *             71000000.             0.0960          1.371E-05          2.780E-09            0.002820
                                                                                                        -------------
                                                                                            Total             0.5515
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      4.05
```

```
                    OPTION 15

Scaling:   BODY_WEIGHT    Species:    RAT    Model:  QUADRATIC
Response of  5 percent corresponds to dose in man of  253,0 mg/kg/day which implies lambda =      8,015E-07
Option cost (millions of dollars) =  3,50  Cost per cancer case (millions of dollars) =  1,00

                                                                            Expected Lifetime        Expected
    Type of                        Number in          Average Annual Exposure           Incidence           Annual Cases
    Person                     U. S. Population  (micro gms/cubic m)     (mg/kg/day)   (probability/lifetime)  (number/year)
    ------                     ----------------  -------------------     -----------   ----------------------  ------------

Machine Operators
-----------------
    Commercial                     16000.             14400.                2,06          3,391E-06              0,000775
    Industrial                       700.             28800.                4,11          1,359E-05              0,000136
    Coin-Up                        11000.              2640.              0,3771          1,140E-07             1,791E-05

Other Workers
-------------
    Commercial                    110000.              4900.              0,7000          3,927E-07              0,000617
    Industrial                     20000.              6400.              0,9143          6,699E-07              0,000191
    Coin-Up                        22000.              2640.              0,3771          1,140E-07             3,582E-05

Service Users
-------------
    Commercial Dry Clean        50000000.              2,45             0,000350          9,816E-14             7,012E-08
    Coin-Op Dry Clean           25000000.              5,00             0,000714          4,088E-13             1,460E-07
    Coin-Op Laundry             37000000.              1,67             0.000239          4,572E-14             2.417E-08

Urban Residents
---------------
     25 -  200 *                 3700000.              1,68             0,000240          4,616E-14             2,440E-09
    200 -  500 *                20000000.            0,2880             4.114E-05         1,356E-15             3,876E-10
    500 - 1000 *                71000000.            0,0960             1.371E-05         1,507E-16             1,529E-10
                                                                                                            -------------
                                                                                            Total               0,001773
* Distance from dry cleaner in meters

Total cost of option and expected cancer (millions of dollars) =      3,50
```

PART III

DI-ETHYLHEXYL PHTHALATE:
A CASE STUDY OF THE APPLICATION OF DECISION ANALYSIS TO THE DETERMINATION OF RISK POSED BY A TOXIC CHEMICAL

Part III

CONTENTS

Section — Page

1 INTRODUCTION AND SUMMARY 1-1

2 PLASTICIZERS 2-1
  Phthalate Ester Plasticizers 2-1
  Manufacturing 2-4
  Uses of Phthalate Esters 2-6

3 THE PROTOTYPE PLASTICS INDUSTRY MODEL 3-1
  Purpose of the Model 3-1
  Structure of the Plastics Industry 3-2
  Structure of the Prototype Model 3-4
  Implementation of the Prototype Model 3-9
  Data for the Prototype Model 3-18

4 RESULTS FROM USING THE PROTOTYPE MODEL 4-1
  Base Case Results 4-1
  Regulatory Policy Run Results 4-10
  Sensitivity Analysis Results 4-18

5 POTENTIAL DEVELOPMENT AND USE OF THE ECONOMIC ANALYSIS MODEL 5-1
  Additional Policy and Sensitivity Analysis 5-1
  Further Development of the Prototype Model 5-2
  Summary 5-3

6 REFERENCES 6-1

APPENDIX A: DATA FOR THE PROTOTYPE PLASTICS INDUSTRY MODEL A-1

APPENDIX B: RESULTS OF POLICY AND SENSITIVITY ANALYSIS CASES USING THE PROTOTYPE PLASTICS INDUSTRY MODEL B-1

Part III

FIGURES

Figure — Page

2-1 Formation of a Phthalate Ester from Phthalic Acid and Alcohol 2-2
2-2 Production of Phthalic Anhydride from Naphthalene or Ortho-xylene 2-5
3-1 General Structure of the Plastics Industry 3-3
3-2 Detail of the Plasticizer Sector and Portions of the Feedstock and Plastics Sectors 3-6
3-3 Structure of the Prototype Plastics Industry Model 3-8
3-4 Modeling the Production of DEHP 3-10
3-5 Market Share Curve 3-16
4-1 Base Case Plastics Production 4-4
4-2 Base Case Plasticizer Production 4-5
4-3 Base Case Plastics Demand for Medical Supplies 4-11
4-4 Plastics Production with "Prohibit" Policy 4-15
4-5 Plasticizer Production with "Prohibit" Policy 4-16
4-6 Plastics Production with High Feedstock Prices and "Prohibit" Policy 4-21
4-7 Plasticizer Production with High Feedstock Prices and "Prohibit" Policy 4-22

Part III

TABLES

Table		Page
2-1	Consumption of Plasticizers by Type	2-2
3-1	Estimates of Quantities Produced and Demanded	3-19
3-2	Derivation of Process Economics for PVC Resin	3-21
3-3	Derivation of Process Economics for DEHP	3-21
3-4	Process Economics and Financial Parameters	3-22
3-5	Economic Market Parameters	3-25
3-6	Feedstock Prices	3-26
4-1	Base Case Plastics and Plasticizer Quantities	4-2
4-2	Base Case Plastics and Plasticizer Prices	4-3
4-3	Base Case Average Plastics Prices by End-Use Category	4-6
4-4	Plasticizer and Plastics Prices	4-7
4-5	Base Case Plastics Usage by End-Use Category	4-8
4-6	Base Case Plastics Usage by End-Use Category	4-9
4-7	New Plant Capacity for DEHP in the Base Case	4-12
4-8	Costs to Consumers	4-17
4-9	Sensitivity Test Feedstock Prices	4-19

Section 1

INTRODUCTION AND SUMMARY

In this case study we demonstrate a method for estimating the economic costs of regulating di-ethylhexyl phthalate (DEHP), a widely used plasticizer. Our case study on perchloroethylene addressed a chemical whereby a single predominant exposure route made analysis of control options relatively straightforward. DEHP is representative of chemicals whose uses and potential for substitution are extremely complex. In this case study, we illustrate a methodology for addressing the complex use structure and analyzing the economics of substitution. The economic analysis is developed using a prototype economic model of the plastics industry.

DEHP is a plasticizer, a substance that is combined with plastic resins to make flexible plastic products. About 190,000 metric tons of DEHP are produced and consumed annually in the United States, making it the most widely used single plasticizer. It is used in a variety of commercial and consumer products in which it has considerable economic value. It is not a new chemical and has been in use since the 1930s. DEHP was selected for possible designation under Section 4(f) of TSCA because of bioassay results from the National Cancer Institute (NCI) indicating that DEHP produces a significant number of liver tumors in rats and mice [1].* Subsequent to our case study on DEHP, EPA has decided that DEHP is not an appropriate candidate for designation under Section 4(f) of TSCA at the present time [2].

---

*Under this section, when the Administrator receives information indicating that a chemical substance or mixture presents or will present a significant risk of serious or widespread harm to humans from cancer, gene mutations, or birth defects, he or she must act within 180 days of receipt of such information to initiate appropriate action to prevent or reduce such risk or find that the risk is not unreasonable. In determining whether to designate a chemical under Section 4(f), EPA must decide whether the underlined criteria have been met.

The major focus of this case study is the development and use of a prototype economic model of the plastics industry with emphasis on plasticizers and DEHP in particular. The model was developed to help analyze the economic implications of potential federal actions that might be taken to regulate the production or use of DEHP. The production of several different plastic resins, plasticizers, plastics, and their interactions in the marketplace are represented in the model. The model is a prototype in the sense that it is intended to provide first-order quantitative estimates of changes in market prices and quantities demanded and supplied at a national aggregate level of detail. These changes are difficult to determine, given the complex interaction of substitution among plasticizers. However, the prototype model illustrates such an estimate, and it could be refined to give better estimates.

The prototype model was run and solved for equilibrium quantities and prices for a base case and two regulatory policies. A consumer surplus calculation was used to estimate the economic impact of prohibiting or restricting the production and use of DEHP. A complete ban on DEHP would reduce consumers' surplus on the order of 100 million dollars per year. Eliminating the use of DEHP from medical applications and automobile interiors would have an annual loss of consumers' surplus on the order of three million dollars.

This part of the report consists of five sections. Section 2 gives an overview of the plasticizer industry. Section 3 describes the prototype plastics industry model, and Section 4 presents the results of the model. Section 5 describes potential development and use of the economic model.

Section 2

PLASTICIZERS

Plasticizers are substances that are mixed with plastic resins to make flexible products. Several different types of plasticizers and individual plasticizers within each type are on the market today. They are used either singly or in combination to achieve desirable processing characteristics and product properties. Table 2-1 lists the major types of plasticizers and their estimated consumption in the United States. In 1979, the estimated consumption of plasticizers was 752,000 metric tons [3]. At an average price of $0.46 per pound [4], the value of these plasticizers in 1979 was $763 million.

From Table 2-1, phthalates (also called phthalate esters) accounted for 509,000 metric tons or about two thirds of total plasticizer consumption. The single most widely used plasticizer, DEHP, is estimated to comprise about 25 percent of the consumption of phthalate esters [4].

PHTHALATE ESTER PLASTICIZERS

An ester is an organic compound formed by the reaction of an acid with an alcohol. The use of different alcohols, such as methanol, ethanol, or butanol, results in different esters. Phthalate esters are formed from phthalic acid, which consists of a single benzene ring with two adjacent carboxylic acid groups. Figure 2-1 shows formation of a generic phthalate ester [5]. In the figure, the letter R stands for an alkyl radical, such as methyl or ethyl, which is a carbon chain having the general formula C_nH_{2n+1}.

The names of the phthalate esters are derived from the names of the alkyl groups from which they are composed. If the two alkyl groups are the

Table 2-1

CONSUMPTION OF PLASTICIZERS BY TYPE (IN THOUSAND METRIC TONS)

Plasticizers	1977	1978	1979
Adipates	28	29	32
Azelates	5	5	5
Epoxy	54	57	59
Linear Phthalates	142	154	157
Phthalates, Other	336	346	352
Polyesters	24	24	25
Trimellitates	12	14	14
Others	103	105	108
Total	704	734	752

Source: Modern Plastics [3]

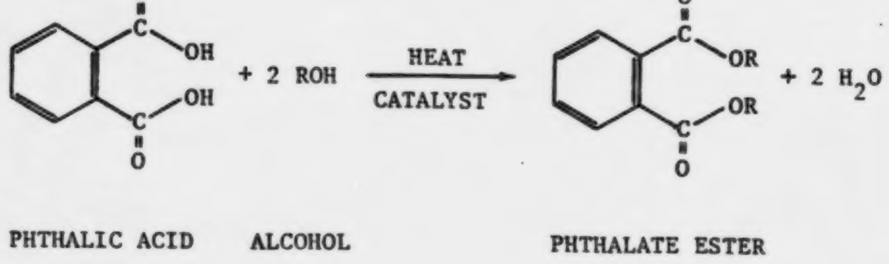

+ 2 ROH
HEAT
CATALYST
+ 2 H2O
PHTHALIC ACID
ALCOHOL
PHTHALATE ESTER

Figure 2-1. Formation of a Phthalate Ester from Phthalic Acid and Alcohol

same, the name is preceded by the prefix di. For example, diethyl phthalate (DEP) has two ethyl radicals. If the radicals are different, the two names are given separately; e.g., butyl decyl phthalate (BDP) contains a butyl (4 carbons) and a decyl (10 carbons) radical. Commercial preparations of mixed esters such as BDP also contain significant quantities of the diesters (DBP and DDP), since they are all produced together and are impractical to separate.

The most commonly used group of plasticizers is dioctyl phthalate (DOP), which contains two octyl radicals, each consisting of eight carbon atoms and seventeen hydrogen atoms. Actually, the radicals with longer chains, such as the octyl radical, can have structures of their own, called branching. The ethylhexyl radical is a form of the octyl radical with a main body of six carbons (hexyl) and a branch with two carbons (ethyl). Another form is the isooctyl radical, which has random branching. The corresponding esters are diethylhexyl phthalate (DEHP) and diisooctyl phthalate (DIOP). The form of DOP with straight alcohols is called di-n-octyl phthalate (DNOP).

The basic differences among the phthalate esters are their molecular weight (corresponding to the number of carbon atoms in the alkyl radicals) and their extent of branching. When phthalate esters are used as plasticizers, increasing the molecular weight generally decreases the compatibility of the ester with the plastic resin and decreases its efficiency of imparting flexibility to the plastic at room temperature. Conversely, increasing molecular weight lowers volatility, thus improving retention of the plasticizer in the product. Increased branching improves compatibility but increases volatility, slightly reduces efficiency, and reduces the low temperature properties of the product. Because of volatility, dibutyl phthalate (DBP) is the lowest molecular weight ester used as a general plasticizer; and because of low compatibility, ditridecylphthalate (DTDP) is about the highest molecular weight ester used as a plasticizer. In many applications, the esters that have radicals with seven to ten carbons have the most useful combination of properties.

Of course, another commercially important property is the cost. Manufacturing branched alcohols is generally less costly than manufacturing straight alcohols, since the corresponding feedstocks are less costly. Therefore, the branched phthalate esters, such as DEHP, are less expensive than the straight (normal) esters. The branched esters were also introduced earlier into the plasticizer market, since the process for manufacturing straight alcohols from petroleum is relatively new. Previously the straight esters could be made only from coconut oil, which is high in straight chain hydrocarbons.

MANUFACTURING

This section briefly describes the process of manufacturing phthalate esters and products containing phthalate esters.

Manufacturing Phthalate Esters

As just described, phthalate esters can be formed by combining phthalic acid with alcohols. The commercial process actually uses phthalic anhydride, which is phthalic acid minus one water molecule [5]. Phthalic anhydride is produced from either of two feedstocks: naphthalene or ortho-xylene. Naphthalene and ortho-xylene occur naturally in coal tar. However, most of these feedstocks are manufactured from crude oil. Through the process of "catalytic reforming," petroleum fractions of aliphatic hydrocarbons (straight carbon chains) are converted to the desired aromatic compounds (compounds with carbon rings) [6]. The naphthalene and ortho-xylene are then separated out of the products by distillation or crystallization.

The production of phthalic anhydride follows the formulas shown in Figure 2-2. Either naphthalene or ortho-xylene is oxidized, usually as a vapor mixed in air and in the presence of a catalyst, to produce phthalic anhydride and combustion products such as carbon dioxide and water.

The alcohols used to produce phthalate esters are made in a variety of ways, depending on size and branching [6]. The smallest molecular weight alcohol, methanol, can be made from many feedstocks, such as coal or natural gas. The next smallest, ethanol, is usually made from such vegetable products as grain. The higher molecular weight alcohols, such as

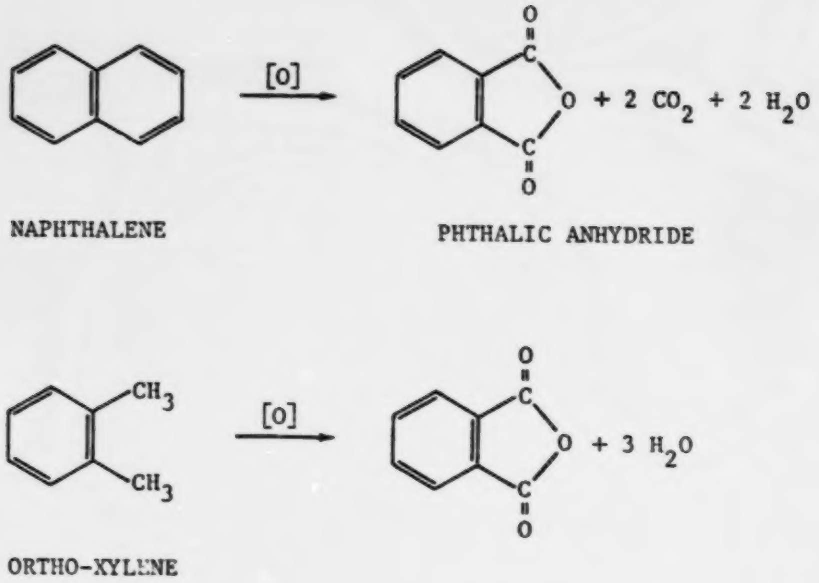


Figure 2-2. Production of phthalic anhydride from naphthalene or ortho-xylene.

octanol, are made from propylene and butylene, which are products of crude oil cracking. Randomly branched alcohols can be produced by a process called hydroformulation, in which high molecular weight olefins are converted directly to alcohols. Alcohols with specifically desired structures are usually built from ethylene.

Manufacturing Plasticized Products

Because 80 percent of all plasticizers are used in polyvinyl chloride (PVC) [7], we will concentrate on the production and uses of plasticized PVC. By itself, PVC is a rigid plastic that becomes brittle at 0°C (32°F). However, when mixed and fused with a plasticizer, such as a phthalate ester, it becomes a tough but flexible product. The plasticizer acts as an internal lubricant, overcoming attractive forces between the chains of PVC and separating them to prevent intermeshing. The degree of flexibility is determined by the concentration of plasticizers, which may compose 30-40 percent of a final PVC product [7].

The action of the plasticizer can be illustrated by considering water as a plasticizer for gelatin. In nonplasticized form, gelatin is a powdered, nonflexible solid. However, when mixed with water, heated, and then cooled, it becomes a soft, flexible solid.

Several ways exist for making plasticized PVC products. Most commonly, powdered PVC and plasticizers are mixed and heated to 150-170°C, the temperature at which the materials fuse or dissolve. While hot, they are formed by calendering (rolling), extrusion, injection molding, spreading, dipping, or pressing. Another procedure is to mix very finely powdered PVC with the plasticizer at room temperature and then use the liquid mixture, called a vinyl dispersion, to spray, pour, spread, or dip a product. After it is formed, the product can then be heated to fuse the PVC and plasticizer, creating a flexible solid.

USES OF PHTHALATE ESTERS

Phthalate esters, particularly those with higher molecular weights, are used primarily as plasticizers. The following are but a few of the many PVC plasticized products containing phthalate esters, including DEHP [8]:

- Shower curtains
- Rainwear
- Inflatable toys
- Tablecloths
- Floor covering and floor tiles
- Insulation (roof, water tank)
- Adhesive tape and film
- Food packaging
- Garden hoses
- Wire covering
- Footwear

- Upholstery
- Handbags
- Coated tubing (bed frames, chairs, plastic racks)
- Gloves
- Gaskets
- Automobile components (crash pads, instrument panels, vinyl tops)
- Medical tubing
- Blood bags

In addition to functioning as plasticizers, some of the lower molecular weight phthalate esters have other uses. Dimethyl phthalate is used as an insect repellent. Diethyl phthalate, because of its bitter taste, is used as a denaturant for alcohol, especially in cosmetics. Several phthalate esters can also be used as solvents [9].

Section 3

THE PROTOTYPE PLASTICS INDUSTRY MODEL

In this section, we discuss the purpose of the plastics industry economic model, describe its structure and underlying assumptions, and summarize the data used and their sources. Section 4 includes a full discussion of the results obtained from using the model. A key insight is that although the economic costs of a total ban on DEHP would be great due to the large quantities in use, a restriction on its use in selected sensitive markets would be significantly less costly because of the availability of substitute materials. In Section 5, we discuss the possible extensions to the prototype model and summarize the capabilities of the modeling approach used in this case study.

PURPOSE OF THE MODEL

What would be the economic impact of prohibiting the production or use of DEHP, restricting its uses, or limiting the quantities used? What would be the costs of using substitute materials? Our prototype model is intended to help answer questions such as these--questions that are critical to a regulatory decision regarding DEHP. The model will also be useful in understanding the implications on the plastics industry of changes in the prices of feedstocks derived from fossil fuels and of variations in plastics demand growth over time.

We use the questions one wishes to answer, together with our information about the plastics industry, to guide the development of the model. The level of detail and required areas of emphasis are defined largely by the three regulatory alternatives considered:

1. No action.

2. Prohibit all manufacturing and use of DEHP.

3. Prohibit the use of DEHP in plastics intended for medical or automobile interior uses.

The focus on DEHP leads to the need for relatively more detail when modeling plasticizers and relatively less for other sectors of the plastics industry. Potential substitutes for DEHP are of particular importance, as are other plasticizers currently competing with DEHP. Polyvinyl chloride (PVC) resins and plastics must be modeled carefully, as the bulk of DEHP is used to plasticize PVC. Because we are interested in decisions concerning plasticizers, we will emphasize flexible plastics.

We chose to develop the prototype model on a national aggregate quantity level. This is sufficient to demonstrate the modeling approach and to provide first-order estimates of the economic impacts. It would be a straightforward task to expand the prototype model in order to examine regional effects or international trade impacts.

STRUCTURE OF THE PLASTICS INDUSTRY

The structure of the model is meant to represent the structure of the relevant portion of the plastics industry. The industry itself can be thought of as composed of three distinct sectors: the production of plastic resins, the production of plasticizers, and the production of plastic products using either plasticized or unplasticized resins. Figure 3-1 depicts these three sectors, together with a sector representing the supply of feedstocks to the plastics industry and a sector representing the demand for plastic products. As the figure indicates, one can think of materials flowing up the economic network, from fossil fuel or other feedstocks, through conversion to plasticizers and resins, to the manufacturing of plastic products, and finally to the end users. This represents the sequence of industrial stages and market transactions from raw materials to final goods.

Within each sector is a variety of industrial and economic processes. Plastic resins, for example, include PVC (which can be produced in several grades), polyethylene (PE), polypropylene (PP), and polystyrene (PS).

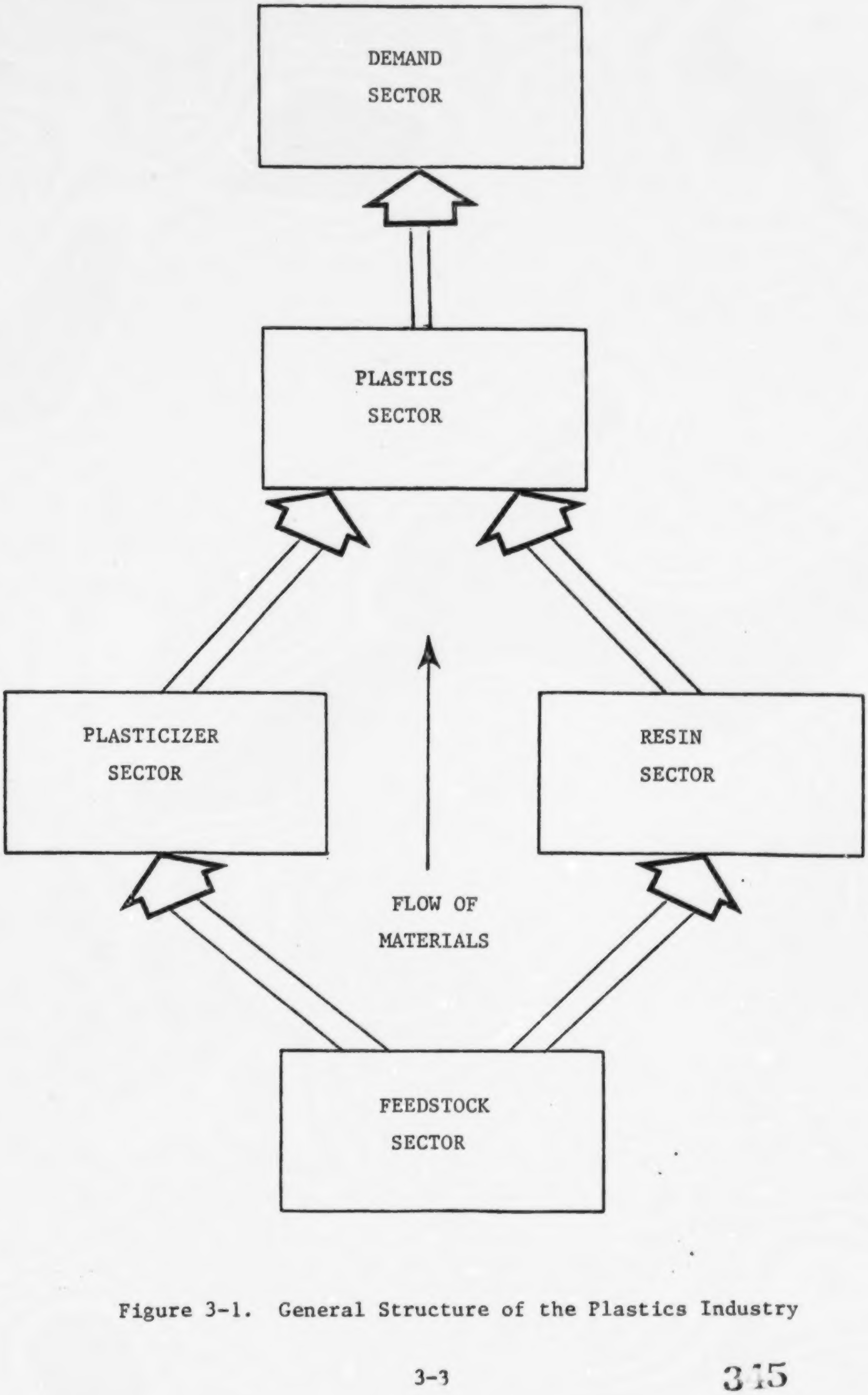

DEMAND
SECTOR
PLASTICS
SECTOR
PLASTICIZER
SECTOR
RESIN
SECTOR
FLOW OF
MATERIALS
FEEDSTOCK
SECTOR

Figure 3-1. General Structure of the Plastics Industry

They are produced from feedstocks such as ethane, propane, and BTX (butylene-toluene-xylene).

PVC resins and a portion of other resins are combined with plasticizers in the plastics sector. Plasticizers compete on the basis of price and properties, including volatility, ease of processing, and plasticity effectiveness. Volatility is of particular importance, as it determines in part both the degree to which the plasticity lasts and the extent to which people are exposed to the plasticizer. Different types of plastics products represent different markets for plasticizers, depending on the nature of the goods and their intended uses. For many uses, such as in construction, the ratio of plasticizer price to its effectiveness is the dominant criterion. For others, including medical uses, low volatility is important.

STRUCTURE OF THE PROTOTYPE MODEL

In our description of the structure of the model on a sector-by-sector basis, we shall first discuss the degree of detail and assumptions used in each sector and then describe the representation of market interactions among sectors.

Guided by the purposes of the model just summarized, we chose to represent plasticizers by the following categories:

1. DEHP--the most widely used phthalate ester plasticizer and the object of toxic substances regulatory analysis.

2. Other large molecular weight phthalate esters--these plasticizers, which include di-isodecyl (DIDP), iso-octyl, and di-isononyl phthalate esters, have properties roughly similar to DEHP and compete primarily on the basis of price and plasticizing ability.

3. Small phthalate esters--these plasticizers include di-ethyl and di-methyl phthalate ester, are more volatile than DEHP, and are used to a significant degree to plasticize resins other than PVC.

4. Very large molecular weight phthalate esters--this category includes both polymerized phthalates and such large molecular size substances as di-tridecyl phthalate ester. They are more expensive but have significantly lower volatility.

5. Epoxidized soy oil--this plasticizer, while relatively expensive, has several desirable properties, including low volatility. It is produced in part from a renewable resource and thus may be less affected by increases in the price of fossil feedstocks.

6. Other primary plasticizers--these include adipic acid esters and phosphoric acid esters. They compete primarily with DEHP and the other large molecular weight phthalate esters.

A portion of the prototype model, including the plasticizer sector, is shown in Figure 3-2. Boxes represent industrial production or conversion processes. Circles represent economic markets, that is, the competition among various products and users of products. The term allocation is used to reflect the market process of allocating goods among the competing firms and industries. The equations used to represent each industrial or market process are discussed in the following subsection.

Only three distinct categories of plastic resins were included in the resins sector of the prototype model. This was felt to be adequate, given the purpose of analyzing toxic substances regulatory decisions concerning plasticizers. The resins represented are PVC, polyethylene, and a category called "other resins." PVC resin is almost always plasticized, thus forming a major part of the demand for DEHP and other plasticizers. PE is the resin used in greatest quantities to produce flexible plastics, and PE plastics often compete with plasticized PVC. The "other resins" include polypropylene and polystyrene, both of which are used to produce plastic products that compete with PVC and PE.

We included five types of plastic in the plastics sector:

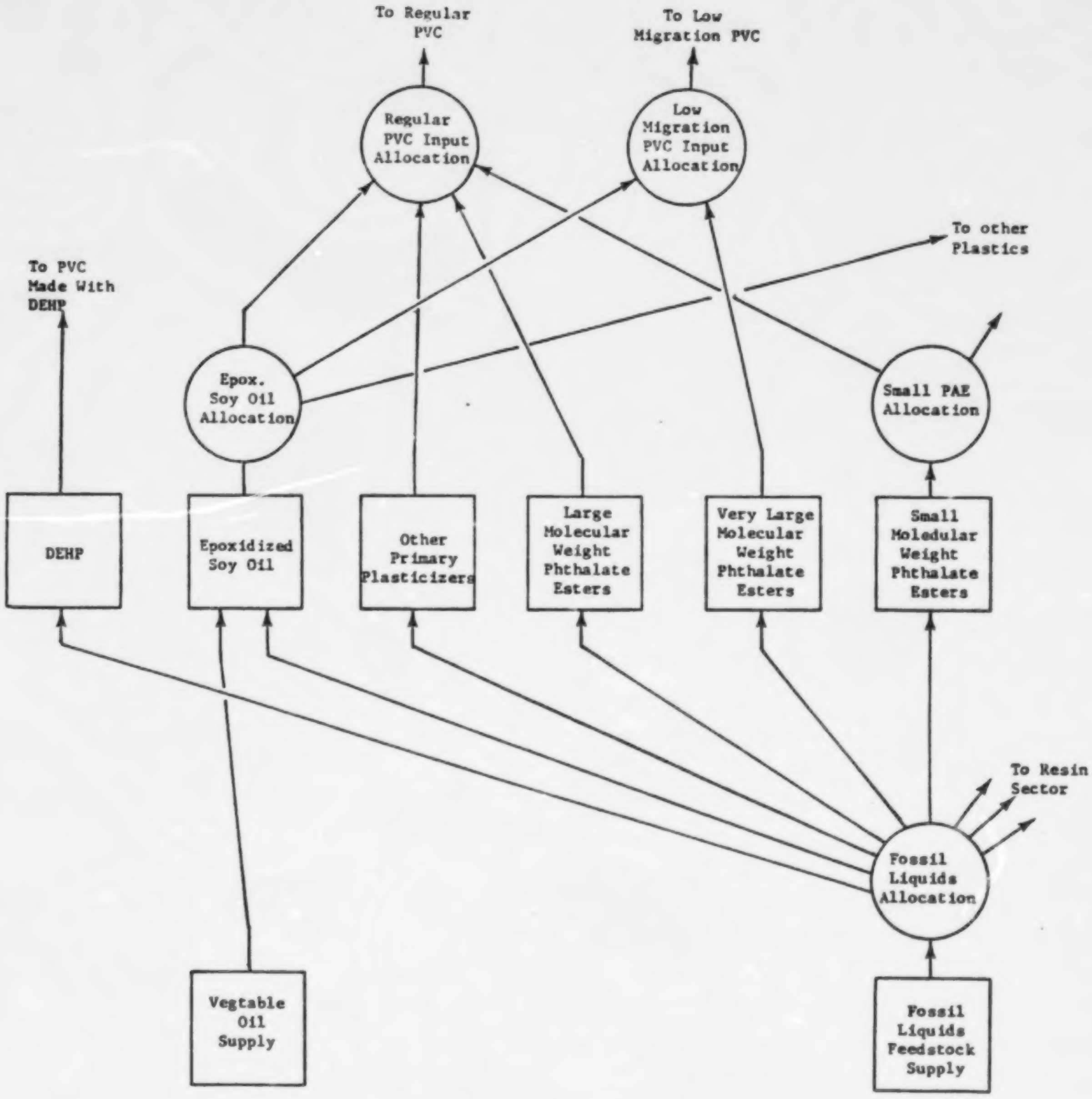
1. PVC plastic using DEHP--this material is the focus of the analysis and is important to examine separately.

2. Regular PVC--this includes all PVC plastic other than that made using DEHP and the special low-volatility/low-migration PVC plastics. These materials compete against PVC with DEHP.

3. Low-migration PVC--this is PVC plastic optimized to cut down on the volatility of the plasticizer. This increases the life of the material and cuts down on the potential for human exposure to the plasticizers. It is plasticized by either epoxidized soy oil or the very large molecular weight phthalate esters.

4. Polyethylene plastic--PE does not need to be plasticized to be flexible. It is the most used plastic in the markets studied.

347



To Regular PVC
To Low Migration PVC
Regular PVC Input Allocation
Low Migration PVC Input Allocation
To other Plastics
To PVC Made With DEHP
Epox. Soy Oil Allocation
Small PAE Allocation
DEHP
Epoxidized Soy Oil
Other Primary Plasticizers
Large Molecular Weight Phthalate Esters
Very Large Molecular Weight Phthalate Esters
Small Moledular Weight Phthalate Esters
To Resin Sector
Fossil Liquids Allocation
Vegtable Oil Supply
Fossil Liquids Feedstock Supply

Figure 3-2. Detail of the Plasticizer Sector and Portions of the Feedstock and Plastics Sectors

318

5. Other plastics--the other flexible (sometimes requiring plasticizers) plastics modeled are polypropylene and polystyrene.

Each of the plastics competes in several end-use market categories in the demand sector. The manner in which we disaggregated plastic demand was determined directly by the nature of the decisions under study. The categories are as follows:

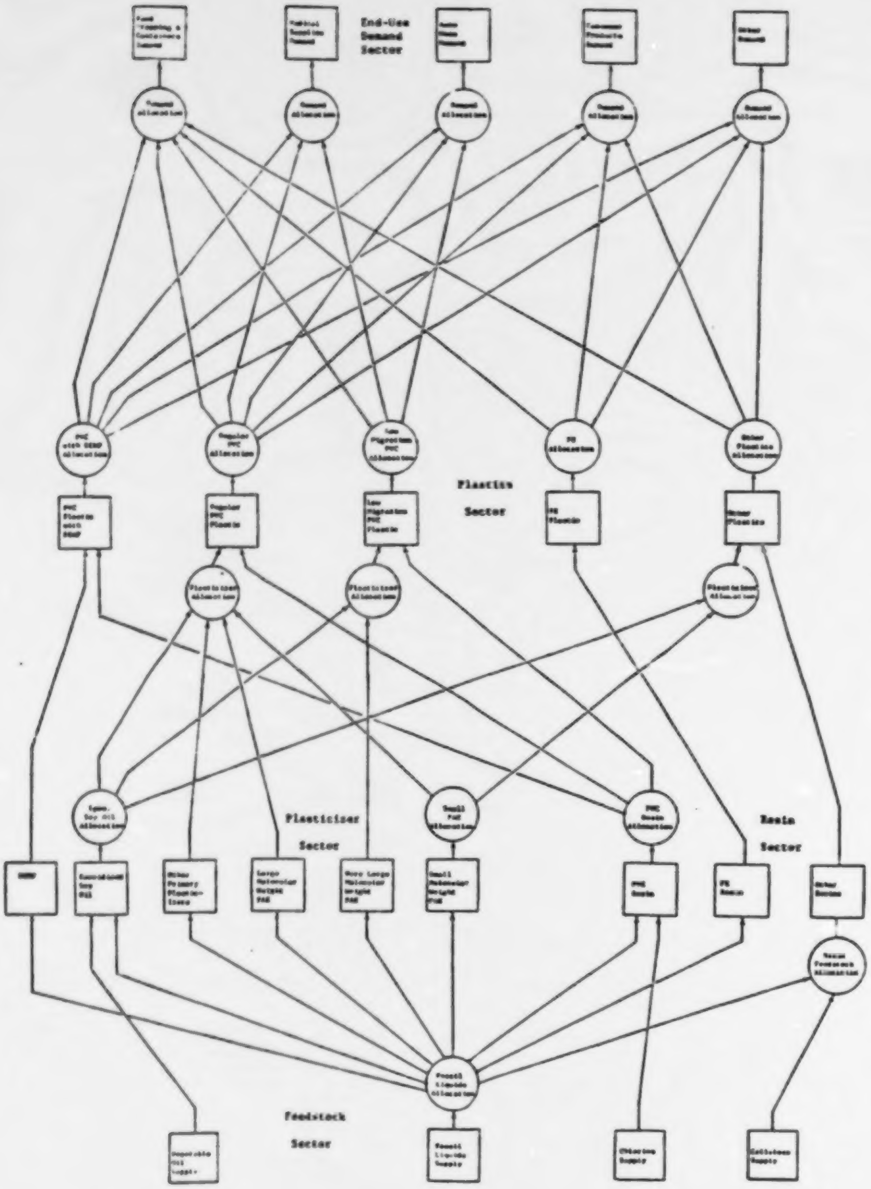
1. Food wrapping and packaging--includes plastic wrap and bags, bottles, cartons, disposable cups and plates, and other products. These products have a relatively high potential for human exposure through skin contact and ingestion of food containing plasticizers.
2. Medical supplies--tubing, blood bags, and so forth. These products have a very high potential for human exposure through contamination of blood or other fluids.
3. Automobile interiors--primarily vinyl seat cushions, trim, and interior linings. These products can have a moderate potential for human exposure under certain conditions.*
4. Consumer products--all consumer products not included in the first or third categories, including housewares, appliances, home siding, luggage, toys, apparel, and recreational products. In most cases, these goods present a low potential for human exposure to plasticizers.
5. All other uses for flexible plastics--primarily industrial (particularly packaging) and construction. The potential for human exposure from these uses is judged to be low.

The low migration PVC plastics play an increasingly important role in the first three demand categories, while plastics other than PVC have only a minimal portion of the medical and automobile interior markets.

The structure of the entire prototype model is outlined in Figure 3-3. It can be thought of as a detailed implementation of the basic structure shown in Figure 3-1. The feedstock sector is quite simple; the fossil liquids supply model represents a generic feedstock. A simplifying assumption was made to aggregate the feedstocks rather than to include

---

*Information available at the time the prototype model was developed indicated that DEHP was used in a significant portion of automobile interior plastics. This use may have since been replaced by alternative materials.


Food Wrapping & Containers Demand
Medical Supplies Demand
End-Use Demand Sector
Consumer Products Demand
Other Demand
Demand Allocation
PVC with DEHP Allocation
Regular PVC Allocation
Low Migration PVC Allocation
PE Allocation
Other Plastics Allocation
Plastics Sector
PVC Plastic with DEHP
Regular PVC Plastic
Low Migration PVC Plastic
PE Plastic
Other Plastics
Plasticizer Allocation
Epox. Soy Oil Allocation
Plasticizer Sector
Small PAE Allocation
PVC Resin Allocation
Resin Sector
DEHP
Epoxidized Soy Oil
Other Primary Plasticizers
Large Molecular Weight PAE
Very Large Molecular Weight PAE
Small Molecular Weight PAE
PVC Resin
PE Resin
Other Resins
Resin Feedstock Allocation
Fossil Liquids Allocation
Feedstock Sector
Vegetable Oil Supply
Fossil Liquids Supply
Chlorine Supply
Cellulose Supply

Reproduced from best available copy.

Figure 3-3. Structure of the Prototype Plastics Industry Model

individual hydrocarbons such as ethane, propane, and BTX. Such detail at the feedstock level was unnecessary due to the emphasis on plasticizers and PVC plastics.

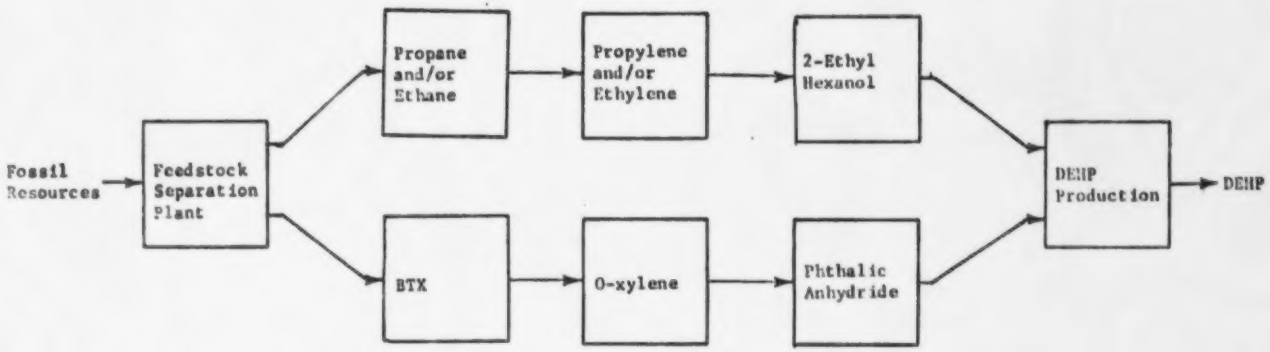
The plasticizer and resin sectors have no direct interactions, but both are drawn on the same feedstock market and are input factors to the plastics sector processes. The plastics and demand sectors have a rich set of interactions: each plastic competes in several end-use markets, while each market draws on several types of plastics.

A key simplifying assumption that helped keep the prototype model at a manageable size was to represent what might be a sequence of industrial processes (which may or may not be in the same physical plant) as a single process of converting one or two primary inputs to a single primary output. This was particularly important in modeling the resin and plasticizer sectors. As an example, consider the production of DEHP. The top portion of Figure 3-4 shows the full sequence of steps required to produce DEHP. As noted, the fossil liquids supply model is used to represent several feedstocks, including propane, ethane, and BTX. The DEHP conversion process represents the combination of all the steps from primary feedstocks through production of DEHP. The process economics represented in the prototype model DEHP conversion process is the net result of the full sequence of steps. We felt that the detail required to model all steps individually would not lead to any significant additional insights. Such detail could be added to the model if it were felt to be necessary.

IMPLEMENTATION OF THE PROTOTYPE MODEL

The prototype plastics industry model represents a portion of the national economy. A number of economic markets in which products compete are included explicitly. To answer the questions presented earlier in this section, it is necessary first to solve for equilibrium prices and quantities in each of the key markets and then to see how these equilibrium values change over time and under different regulatory alternatives.

Given the nature of the plastics industry and the regulatory issues, we chose to implement the prototype model using an approach known as generalized equilibrium modeling [10]. This methodology characterizes the


Fossil Resources
Feedstock Separation Plant
Propane and/or Ethane
Propylene and/or Ethylene
2-Ethyl Hexanol
BTX
O-xylene
Phthalic Anhydride
DEHP Production
DEHP

Full Sequence of Steps Required to Produce Di-ethylhexyl Phthalate Ester

Simplified Representation Used in the Prototype Model

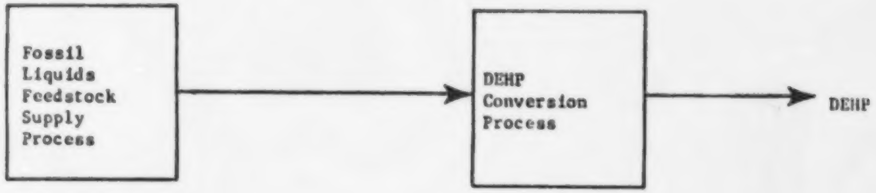

Fossil Liquids Feedstock Supply Process
DEHP Conversion Process
DEHP

Figure 3-4. Modeling the Production of DEHP

economy (or a portion thereof) as a system of economic agents who interact through explicit markets and who make economic decisions at each step from feedstock production to end use of a product by consumers.

At any time, the state of an industry is determined by the results of the decisions made by the agents in the industry. It is the interactions of these uncoordinated decisions that determine the prices and quantitites of the chemical substances or other materials produced by each available industrial process. The decisions made by these agents will determine the reaction of the industry both to government policies such as taxes, regulations, and subsidies and to other changes in the economy, such as those caused by inflation, embargoes, or changes in the cost of various input factors.

Generalized equilibrium models consist of three basic elements:

1. Process submodels that describe the decision-making behavior of agents in the economy.
2. A network that describes the way that agents in the economy interact.
3. An algorithm that solves the model to obtain the equilibrium set of prices, quantities, and capacity additions.

A process is defined as a model of a subsystem or sector of the overall system being modeled and is characterized by a set of mathematical relations or equations that are formalized as computer code. These relations are derived from the underlying decision-making behavior of the economic agent or agents being modeled. In each process, two types of relationships can be distinguished. The first consists of physical relationships that describe how physical flows interact over time. An example of a physical relationship is the amount of plastic resin produced per ton of petroleum feedstock for a particular chemical process. The second type consists of behavioral relationships that describe the choices that decision makers make in operating plants. An example would be the decision of a plasticizer producer of whether to shut down production or continue operating plants if a regulatory action substantially changes his process economics.

A network defines the economic and material links among the processes in a model. Figure 3-3, the diagram we used to describe the structure of the plastics industry, is already in the network form required. In this network, the links represent flows of chemical products. Associated with each flow is a price and quantity of the product. At the top of the network are processes that describe the end-use demands; at the bottom are processes that describe feedstock production and supply. In between is a network of other processes that describe market behavior, conversion, and (if important) transportation in the entire economic system. One can think of materials flowing "up" the network, with prices being communicated "down" the links.

The algorithm used to solve a generalized equilibrium model must find the set of price and quantities that simultaneously satisfy all the physical and behavioral relations embodied in the processes and the links among the variables as defined by the network. The algorithm used to solve the problem should take advantage of the natural structure of a particular model rather than impose arbitrary restrictions on the problem structure.

The particular algorithm used is a form of successive approximations with relaxation. The first step in the algorithm is to provide a guess of all quantities of goods and materials produced or used by each process for each time period. Prices at which the required quantities of primary resources or feedstocks will be supplied are computed by resource process models or, as in the case of the plastics industry model, supplied as inputs. The algorithm then works its way "up" the network, using the process models to calculate output prices (of resins, plastics, and so on) based on factor input prices (from "lower down" the network) and other process data. When the "top" of the network is reached, prices of end-use goods are used to compute demand quantities. The quantities then flow "down" the network, with quantities of plastics being used to compute required quantities of resins and plasticizers, and the quantities of the latter two sets of substances used to compute required quantities of feedstocks. The quantities calculated on this "downpass" through the network now form a new guess for the equilibrium quantities. This improved guess is used as the basis for another pass "up" the network computing prices and market shares.

The algorithm continues in this manner, going up (computing prices) and down (computing quantities) the network until the prices and quantities do not change (within a tolerance of a few percent) from one iteration to the next. At this point, the algorithm has converged to a set of prices and quantities that balance supply and demand and satisfy all physical and behavioral relations in the model. A simple relaxation scheme is used to speed convergence.

DFI has developed a set of computer software to facilitate the implementation of economic market models. These software tools are known as the Generalized Equilibrium Modeling System (GEMS) and the Model Data Management System (MDMS) [11,12,13]. The GEMS software includes the capability to specify economic networks, a successive approximations algorithm used to solve for equilibrium, and the necessary process models. MDMS provides the tools to enter data for the model and to record and display the results of running the model. Both data and results will be discussed in the following paragraphs.

Three GEMS process models were used to implement the prototype plastics industry model:

1. The conversion process, which represents a firm (or aggregation of similar firms) producing an output product from a set of inputs.

2. The allocation process, which models the allocation of supply and demand in a competitive market.

3. The end-use demand process.

The conversion process uses a set of equations developed from the assumption that the owners of a plant will make decisions that tend to maximize discounted cash flow or some other measure of discounted profit. Decisions made at each time point are based on forecasts of market prices for both output products and factors of production. Necessary additions to productive capacity are modeled explicitly, and the different "vintages" of plants (which may have different operating costs and efficiencies) are tracked individually. The basic equation used to determine product prices over time is as follows:

$$P(t) = \frac{ECC(t)}{CF(t)} + VOC(t) + \sum_{i} IO_i(t) * P_i(t) \tag{1}$$

where

$P(t)$ = output price at time t (of, e.g., a particular resin, plasticizer, or plastic).

$P_i(t)$ = price of input factor i at time t.

$ECC(t)$ = effective capital cost per unit of output at time t. ECC is a function of plant cost, plant capacity, and financial parameters including book and debt life, cost of capital, and tax rates. It represents the effective after-tax cost to the firm of the amount of capacity needed to produce one unit of output per year.

$CF(t)$ = capacity factor, that is, the ratio of actual production to the capacity of the plant. This reflects the fact that the plant is not operated at full capacity all the time, due to breakdowns or other factors.

$IO_i(t)$ = the input-output coefficient for primary input factor i (e.g., the number of units of the factor i needed to produce one unit of the output good). These are the input factors of production explicitly modeled by the links in the economic network.

$VOC(t)$ = all other variable operating costs, including secondary inputs, maintenance, and so on.

Operating and capital costs as well as input-output coefficients can change over time due to technological improvements and other factors. The capacity factor adjusts the effective capital cost ECC(t) to reflect less than full-time use of a plant. The capacity factor is computed based on the cost of operating plants of different ages. Less efficient older plants may be operated less and eventually shut down when they are not economically competitive with new plants. Given the economically efficient level of production (at the price p(t)) from existing plants, new capacity is added to meet demand. If demand is less than the potential production from existing plants (e.g., excess capacity exists), plants are shut down in order of decreasing operating costs. The full set of equations used in the conversion process are documented in [11]. In the prototype plastics industry model we used the conversion process (1), with appropriate data and parameters, to represent the production of plasticizers, resins, and plastic products.

The allocation process model represents a market where buyers and sellers trade for a commodity at a price. Specifically, demands for a commodity are aggregated and allocated among suppliers of that commodity according to their various selling prices.

An allocation process that responds sharply to small changes in prices (as would be the case if the demand were allocated entirely to the lowest price source) would overstate the market response to prices. Thus, the model described here produces allocations that respond continuously to changes in product prices while retaining the flexibility to represent markets ranging from the highly competitive to those where allocation of demand is independent of price. The process also has the flexibility to allow for product discrimination in the marketplace and for market response lags. Thus, by suitable choice of parameters, a wide range of different market situations can be represented.

With no lag in the market response, the market share of the ith supplier is given by

$$MS_i(t) = \frac{f_i \times p_i(t)^{-b}}{\sum_{\text{all } j} f_j \times p_j(t)^{-b}} \qquad (2)$$

where

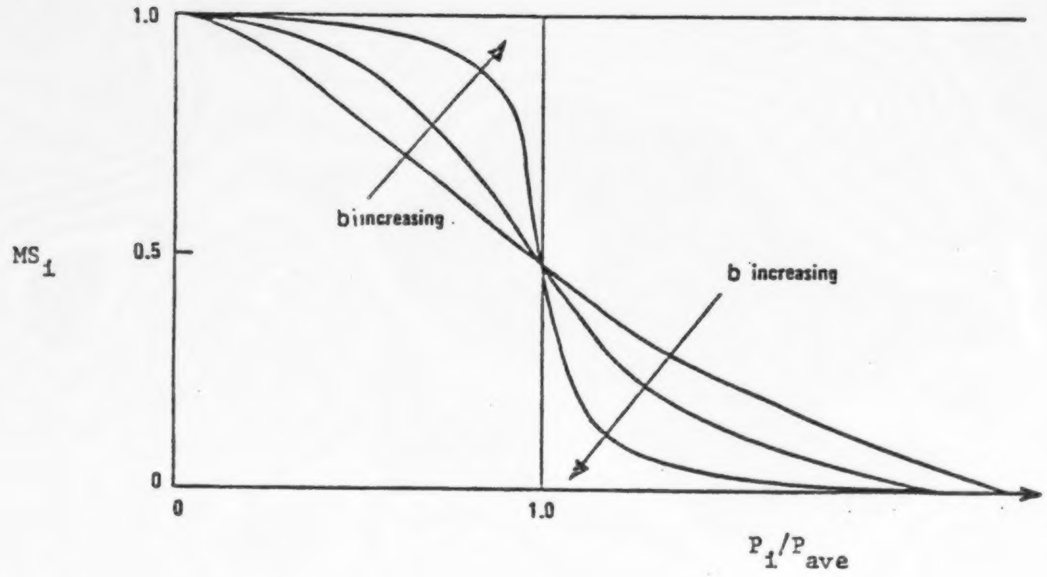
$MS_i(t)$ = market share for supplier i

$P_i(t)$ = price for the commodity from supplier i

b = market-price sensitivity parameter

f_j = fraction of market captured by supplier j when all supplier prices are equal, reflecting buyer's preferences for the product offerings of the different suppliers

The form of this function is depicted in Figure 3-5. The parameter b determines the market-share sensitivity to changes in price. By setting



Note: p_{ave} = average price of competing goods.

Figure 3-5. Market Share Curve

the value of this parameter--the price sensitivity of each allocation process--the user selects the price sensitivty of each process in the model, from a very price sensitive limit to a price insensitive limit. The larger the value of b, the more sensitivity the market share is to price.

The fraction at equal prices parameters f_j provide for the possibility that the product from one supplier is more attractive than that from another for reasons other than price. Low volatility of a plasticizer is an example in the prototype model of a characteristic that may affect buyer preferences among alternative suppliers. The parameters f_j can be set to reflect this kind of product differentiation.

The allocation of demand given by the market share equation assumes that decision makers reallocate demand instantly in response to changes in relative prices. In reality, the response to price changes is slowed by planning lead times and a natural reluctance on the part of the decision makers to change. This aspect of demand allocation is modeled by a behavioral lag coefficient that represents the number of years it takes a market to make one-half of its ultimate response to a change in prices.

The calculation of the prices of the outputs of a market process should reflect the relative share of each source and its price. The allocation of process model further assumes that the price of the outputs of an allocation process are identical and are given by

$$p(t) = \sum_{\text{all } i} p_i(t)\, MS_i(t) \qquad (3)$$

where p(t) is the average price of the output of an allocation process and other terms are as defined earlier.

The end-use demand process represents the changes in demand over time and as a result of price changes. In effect, it is simply a demand function. Input data is used to specify a reference demand quantity in each period given a reference real price. The reference demand is then adjusted for price changes using a constant elasticity demand function. Different short- and long-run elasticities can be specified with the long-run response lagged behind the short-run adjustments.

The form of the demand function is

$$\left(\frac{Q(t)}{\overline{Q}(t)}\right) = \left(\frac{Q(t-1)}{\overline{Q}(t-1)}\right)^{a} \left(\frac{P(t)}{\overline{P}(t)}\right)^{e}$$

where

$Q(t)$ = quantity of product demanded at year t

$P(t)$ = price of product at year t

$\overline{Q}(t)$ = value of reference demand path at t

$\overline{P}(t)$ = value of reference price path at t

a = annual lag coefficient

e = short-run (one year) price elasticity

The lag coefficient depends on the relative values of the short- and long-run price elasticity parameters.

DATA FOR THE PROTOTYPE MODEL

Data for the model were derived from a number of sources, including industry and government publications. The data can be grouped in five rough categories: estimates of quantities supplied and demand during the first period of the model; process economics and financial parameters; market price sensitivity and behavioral lag parameters; prices of feedstocks; and parameters defining the time structure of the model.

Estimates of initial quantities are used by the GEMS software as a starting point from which to solve for supply-demand equilibrium. Quantities of plasticizers, resins, and plastics as well as demand estimates were developed from data in the SRI Chemical Economics Handbook [14], Modern Plastics [15], and the U.S. government publication, Synthetic Organic Chemicals [4]. Initial quantity estimates as of 1978 are summarized in Table 3-1.

Table 3-1

ESTIMATES OF QUANTITIES PRODUCED AND DEMANDED (1978)

Plasticizer Quantities (1000s of metric tons)	
DEHP	189
Large Molecular Weight Phthalate Esters	260
Very Large Molecular Weight Phthalate Esters	18
Small Molecular Weight Phthalate Esters	135
Epoxidized Soy Oil	34
Other Primary Plasticizers	76
Resin Quantities (1000s of metric tons)	
PVC Resin	1,780
PE Resin	4,995
Other Resins	1,640
Plastics Quantities (1000s of metric tons)	
PVC made with DEHP	703
Regular PVC Plastic (non-DEHP)	1,451
Low Migration PVC Plastic	156
PE Plastic	4,755
Other Plastics	1,652
Plastics Demand Quantities (1000s of metric tons)	
Food Packaging, Wrapping, and Containers	1,505
Medical Supplies	34
Automobile Interiors	199
Other Consumer Products	2,127
Other Flexible Plastics Uses	5,021

Process economics data were developed primarily from the SRI Chemical Economics and Process Economics Handbooks [14,16]. The process parameters for many industries represented in the model were derived from a sequence of manufacturing steps. A relatively simple example for PVC resin is shown in Table 3-2. Capital and operating costs for the first stage are scaled by the appropriate input-output coefficient and added to those for the second stage.

A more complex example is the DEHP production process. The sequence of production steps was shown previously in Figure 3-1. The net process economics parameters are derived in Table 3-3. Input-output coefficients were adjusted for relative heat content to account for the single generic feedstock (modeled as an average of propane and ethane).

The process economics and financial parameters for a number of the chemical processes are summarized in Table 3-4. This table is in the form generated by the MDMS software [12] used to store and update data for the prototype model. The feedstock input-output coefficients in column 3 are entered as inverses. The planning lead times indicate how long it takes from the point a decision is made to expand capacity to the point at which the new capacity is available. The year available defines when the particular process technology is available for use; if less than the initial year of the model (as in this case), it has no effect. Columns 6 and 7 contain limit parameters that can be used to model significant technological changes over time; the settings to 1.00 indicate that this capability was not used in the prototype model. The plant life reflects the actual useful life of a plant, while tax and book lives are financial parameters. The equity fraction is used to determine the cost of capital. Availability is the fraction of time the plant is available for production, net of unplanned shutdowns and failures.

The parameters used to define the characteristics of the economic markets were based on a combination of information contained in [14] and [15], together with DFI experience with similar models. The parameters are summarized in MDMS data tables as Table 3-5. The row names correspond to allocation processes (circles) shown in Figure 3-3. Price sensitivity and behavioral lag were defined in the discussion of the allocation process

Table 3-2

DERIVATION OF PROCESS ECONOMICS FOR PVC RESIN

Stage	SCC	VOC	I/O
VC Monomer	$240	$163	ethane 0.53 chlorine 0.59
Polymerization	$564	$136	1.025
Net for PVC Resin	$810	$303	ethane 0.54 chlorine 0.61

Stream Factor (Availability) = 0.9

SCC = specific capital cost, the cost of one unit (metric ton per year) of capacity

VOC = variable operating cost (per metric ton of output)

I/O = input-output coefficient(s), the units of input(s) required to produce one unit of output

Table 3-3

DERIVATION OF PROCESS ECONOMICS FOR DEHP

Stage	SCC	VOC	I/O
Ethylene	$ 363	$ 58	1.40
2-Ethyl Hexanol from ethylene	636	97	1.79
Net for 2-EH from feedstock	1286	201	2.51
O-xylene	132	37	1.12
Phthalate anhydride from o-xylene	407	96	1.02
Net for Phthalate anhydride from feedstock	542	134	1.14
DEHP from 2-EH and Phthalate anhydride	137	71	2-EH 0.69 P.A. 0.39
Net for DEHP from feedstock	1236	262	2.18

Steam Factor (availability) = 0.9

Note: See Table 3-2 for definitions of process parameters

Table 3-4

PROCESS ECONOMICS AND FINANCIAL PARAMETERS

GP = 3 CONVERSION		ATTRIBUTE			
		SPECIFIC CAPITAL COST	VARIABLE OPTING COST	FEEDSTK. I/O COEFF.	PLANNING LEAD TIME
SPECIFIC PROCESS		1	2	3	4
NOT CURRENTLY USED	1	0.00	0.00	0.00	2
DEHP	2	1236.00	262.00	0.46	2
LG. MOLEC WT. PHTHAL EST	3	1187.00	283.00	0.45	2
VY LG. MOL.WT. PAE	4	1187.00	314.00	0.41	2
SM MOL.WT. PAE	5	1069.00	410.00	0.51	2
PE RESIN	6	1100.00	340.00	0.73	2
OTHER RESIN	7	900.00	330.00	0.62	2
PE PLASTIC	8	100.00	50.00	0.97	2
OTHER PRIMARY PLASTICIZE	9	1801.00	306.00	0.42	2

GP = 3 CONVERSION		ATTRIBUTE			
		YEAR AVAILABL	CAPITAL TECH CHG LIMIT	THERMAL EFFIC. LIMIT	CHAR. PLANT LIFE
SPECIFIC PROCESS		5	6	7	8
NOT CURRENTLY USED	1	1970	1.00	1.00	30
DEHP	2	1970	1.00	1.00	30
LG. MOLEC WT. PHTHAL EST	3	1970	1.00	1.00	30
VY LG. MOL.WT. PAE	4	1970	1.00	1.00	30
SM MOL.WT. PAE	5	1970	1.00	1.00	30
PE RESIN	6	1970	1.00	1.00	30
OTHER RESIN	7	1970	1.00	1.00	30
PE PLASTIC	8	1970	1.00	1.00	30
OTHER PRIMARY PLASTICIZE	9	1970	1.00	1.00	30

Table 3-4 (continued)

GP = 3 CONVERSION		TAX LIFE	DEBT LIFE	EQUITY FRACTION	AVAIL-ABILITY
		ATTRIBUTE			
SPECIFIC PROCESS		9	10	11	12
NOT CURRENTLY USED	1	11	20	0.75	0.90
DEHP	2	11	20	0.75	0.90
LG. MOLEC WT. PHTHAL EST	3	11	20	0.75	0.90
VY LG. MOL.WT. PAE	4	11	20	0.75	0.90
SM MOL.WT. PAE	5	11	20	0.75	0.90
PE RESIN	6	11	20	0.75	0.90
OTHER RESIN	7	11	20	0.75	0.90
PE PLASTIC	8	11	20	0.75	0.90
OTHER PRIMARY PLASTICIZE	9	11	20	0.75	0.90

Table 3-5

ECONOMIC MARKET PARAMETERS

GP = 1 BASIC ALLOC.		ATTRIBUTE		
		SHARE PRICE SENSITVY	BEHAVIOR LAG	MIN.QUAN FOR CONV CHECK
SPECIFIC PROCESS		1	2	3
FOS/LIQ ALLOC	1	5.00	3.00	0.02
EPOX SOY OIL ALLOC	2	5.00	3.00	0.02
PVC RESIN ALLOC	3	5.00	3.00	0.02
PVC RESICN ALLOC.	4	5.00	3.00	0.02
PVC/REG PLASTC ALLOC	5	5.00	3.00	0.02
PVC/LOW MIG ALLOC	6	5.00	3.00	0.02
PE PLASTIC ALLOC	7	5.00	3.00	0.02
OTHER PLASTICS ALLOC	8	5.00	3.00	0.02
PVC/DEHP ALLOC	9	5.00	3.00	0.02

GP = 2 SPECIAL ALLOC.		ATTRIBUTE		
		SHARE PRICE SENSITVY	BEHAVIOR LAG	MIN.QUAN FOR CONV CHECK
SPECIFIC PROCESS		1	2	3
VEG/FOS LIQ. ALLOC.	1	5.00	3.00	0.02
CELLULOSE SUPPLY ALLOC.	2	5.00	4.00	0.02
INPUT FACTOR ALLOC-1	3	10.00	2.00	0.02
INPUT FACTOR ALLOC-2	4	10.00	2.00	0.02
INPUT FACTOR ALLOC-3	5	10.00	2.00	0.02
FOOD DEMAND ALLOC	6	10.00	2.00	0.02
MEDICAL DEMAND ALLOC	7	10.00	2.00	0.02
AUTO DEMAND ALLOC	8	10.00	2.00	0.02
CONSMR PROD DMND ALLOC	9	10.00	2.00	0.02
OTHER DEMAND ALLOC	10	10.00	2.00	0.02

model. The minimum quantity for convergence check is used by the iterative convergence algorithm; it avoids checking for convergence in markets with insignificantly small quantities. Larger values of share price sensitivity imply a more price-sensitive market. Smaller values for behavioral lag reflect a more rapid adjustment to price changes.

Future price estimates for feedstocks were developed from information in Synthetic Organic Chemicals [4], Agricultural Statistics [17], and three national energy-economic system models: the Long-Range Energy Analysis Program (LEAP) used by the Energy Information Agency of the U.S. Department of Energy [18], the Integrated Forecasting Model (IFM) used by the Electric Power Research Institute [19], and the Salant Energy Reference Model [20]. Prices over the next twenty years are listed in Table 3-6. The prices for the generic fossil liquid feedstock reflect the cost of conversion from crude oil and natural gas to an ethane/propane mix. All prices are in constant 1978 dollars (that is, they do not include inflation).

Demand was modeled as increasing at an average of three percent per year in the food and consumer products markets, at five percent per year in the medical and automobile markets, and at two percent annually in the market for other plastic goods [15]. Short-run price elasticity is quite low in the plastics end-use markets, with the long-run elasticity being somewhat greater (-0.1 and -0.2, respectively).

The prototype model was set up to run from 1978 to the year 2000, at two-year intervals. This gives both sufficient resolution over time and an adequately long time horizon over which to examine the implications of regulatory actions carried out in the near future.

Complete documentation of the data used in the prototype model is provided in Appendix A. The relative desirability of different plasticizers and plastics are defined by the market fractions and equal prices parameters. These are listed in Table A-5 in Appendix A.

Table 3-6

FEEDSTOCK PRICES
(all prices in $/metric ton)

Year	Fossil Liquid	Chlorine	Vegetable Oils	Cellulose
1978	$ 172	$ 294	$ 620	$ 260
1980	265	312	620	275
1982	288	331	620	290
1984	313	352	620	305
1986	337	372	620	320
1988	358	395	620	340
1990	381	419	620	360
1992	402	436	620	385
1994	424	454	620	410
1996	446	472	620	435
1998	467	491	620	460
2000	489	511	620	490

Section 4

RESULTS FROM USING THE PROTOTYPE MODEL

In this section we will present and discuss the results obtained using the model. Discussion of a nominal or "base case" will be followed by policy cases and feedstock price sensitivity test cases.

BASE CASE RESULTS

The base case assumes no new regulatory actions with respect to plasticizers or plastic resins. The model was run for eleven two-year periods and solved for estimates of resin, plasticizers, and plastics prices and quantities through the year 2000.

Aggregate results for plastics and plasticizers are shown in Tables 4-1 and 4-2 and Figures 4-1 and 4-2. These tables and plots were produced by the MDMS software. The average prices of the mix of plastics used by each demand category are shown in Table 4-3. A portion of the price results are translated into cents per pound in Table 4-4, for the convenience of readers more familiar with these units. The breakdown of types of plastics used by each end-use demand are detailed in Tables 4-5 and 4-6. All quantities are given in thousands of metric tons per year and all prices are in 1978 dollars per metric ton. The quantities shown for the first period differ slightly from the estimates given in Table 3-1. These estimates represent an incomplete description of the market based on the available data. The quantities in Tables 4-1 and 4-2 describe a complete supply-demand balance consistent with the assumptions of the prototype model.

In the base case the use of polyethylene is rising more rapidly than is the use of any other flexible plastic (see Table 4-1 or Figure 4-1). This is consistent with recent trends [15]. The greatest percentage increase is seen for low migration PVC, a more than tripling of use by the

Table 4-1

BASE CASE PLASTICS AND PLASTICIZER QUANTITIES

REPORT # 1

PLASTICS PRODUCTION

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	713.92	1483.57	148.29	4860.78	1679.44
1980	2	774.23	1523.17	177.10	4956.74	1732.27
1982	3	828.16	1577.93	205.80	5118.53	1776.41
1984	4	879.72	1642.63	233.62	5329.81	1817.59
1986	5	930.40	1712.93	260.41	5569.34	1858.40
1988	6	976.38	1777.76	285.81	5844.02	1906.15
1990	7	1020.69	1841.18	311.04	6142.21	1957.47
1992	8	1071.24	1916.59	328.05	6450.11	2008.69
1994	9	1126.59	2000.75	367.27	6768.93	2060.64
1996	10	1186.18	2092.22	399.16	7099.45	2114.52
1998	11	1248.15	2187.16	433.75	7449.76	2173.57
2000	12	1312.85	2286.39	471.79	7818.59	2236.56

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 2

PLASTICIZER PRODUCTION

AF= SUM GSS= QUANTITY		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	199.90	287.24	142.08	21.98	39.21	83.96
1980	2	216.79	299.77	139.55	30.91	36.54	90.56
1982	3	231.88	312.00	139.01	38.26	37.24	97.20
1984	4	246.32	323.95	139.74	43.87	41.08	103.94
1986	5	260.51	335.57	141.31	47.97	47.10	110.68
1988	6	273.39	345.34	143.73	50.88	54.55	116.73
1990	7	285.79	354.13	146.61	52.88	63.56	122.46
1992	8	299.95	364.82	149.77	54.58	73.93	128.79
1994	9	315.45	376.73	153.14	56.06	85.80	135.57
1996	10	332.13	389.58	156.71	57.41	99.18	142.72
1998	11	349.48	402.82	160.65	58.79	113.79	149.96
2000	12	367.60	416.39	164.80	60.14	130.12	157.41

QUANTITIES IN THOUSANDS OF METRIC TONS.[25]

Table 4-2

BASE CASE PLASTICS AND PLASTICIZER PRICES

REPORT # 7

PLASTICS PRICES

AF= AVERAGE PRICE GSS= PRICES		MATERIAL PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	808.54	827.28	886.73	801.16	838.06
1980	2	912.49	932.05	979.55	932.71	996.52
1982	3	945.21	965.16	1008.63	965.42	1036.18
1984	4	980.91	1001.54	1043.81	1000.95	1079.18
1986	5	1015.10	1036.55	1079.02	1035.04	1120.32
1988	6	1047.65	1069.90	1113.10	1064.92	1156.64
1990	7	1082.68	1105.80	1149.86	1097.60	1196.28
1992	8	1112.39	1136.33	1181.16	1127.47	1232.97
1994	9	1143.64	1168.42	1213.75	1158.80	1271.42
1996	10	1175.47	1201.09	1246.61	1190.73	1310.54
1998	11	1205.68	1232.06	1277.64	1219.97	1346.71
2000	12	1236.58	1263.60	1308.54	1250.07	1383.47

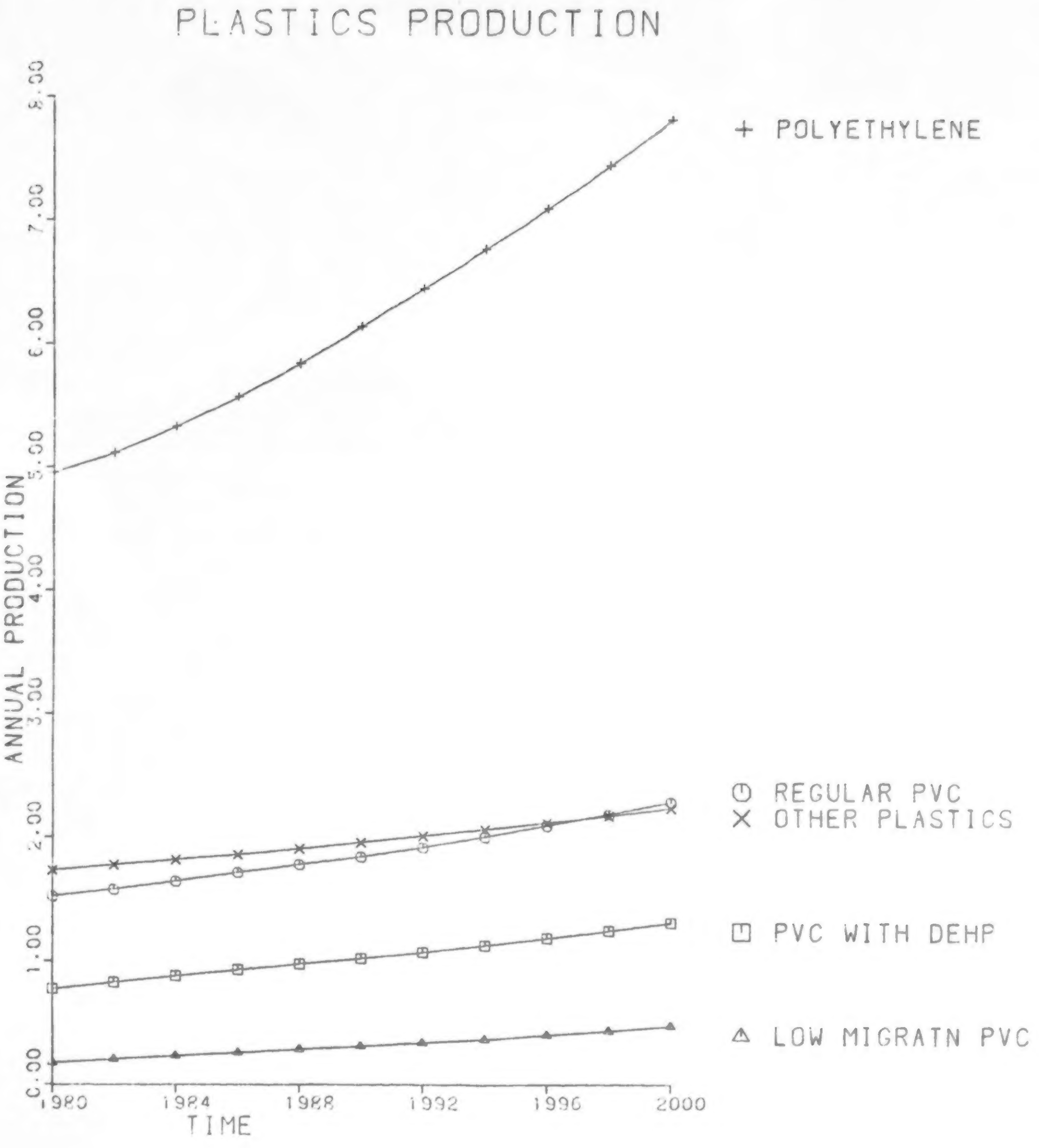
AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 8

PLASTICIZER PRICES

AF= AVERAGE PRICE GSS= PRICES		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	791.98	815.72	884.25	884.74	1280.59	940.79
1980	2	994.42	1022.67	1066.88	1111.89	1435.12	1162.45
1982	3	1044.71	1074.09	1112.27	1168.33	1473.46	1217.49
1984	4	1099.35	1129.94	1161.57	1229.63	1515.11	1277.29
1986	5	1151.77	1183.53	1208.88	1288.45	1555.07	1334.67
1988	6	1197.70	1230.48	1250.32	1339.98	1590.07	1384.95
1990	7	1247.94	1281.85	1295.66	1396.35	1628.37	1439.97
1992	8	1293.85	1328.78	1337.08	1447.85	1663.35	1490.24
1994	9	1341.94	1377.92	1380.45	1501.79	1699.99	1542.90
1996	10	1390.13	1427.18	1423.92	1555.81	1736.49	1595.70
1998	11	1428.42	1466.19	1457.23	1598.71	1764.43	1637.76
2000	12	1479.02	1517.90	1503.14	1655.41	1803.16	1693.26

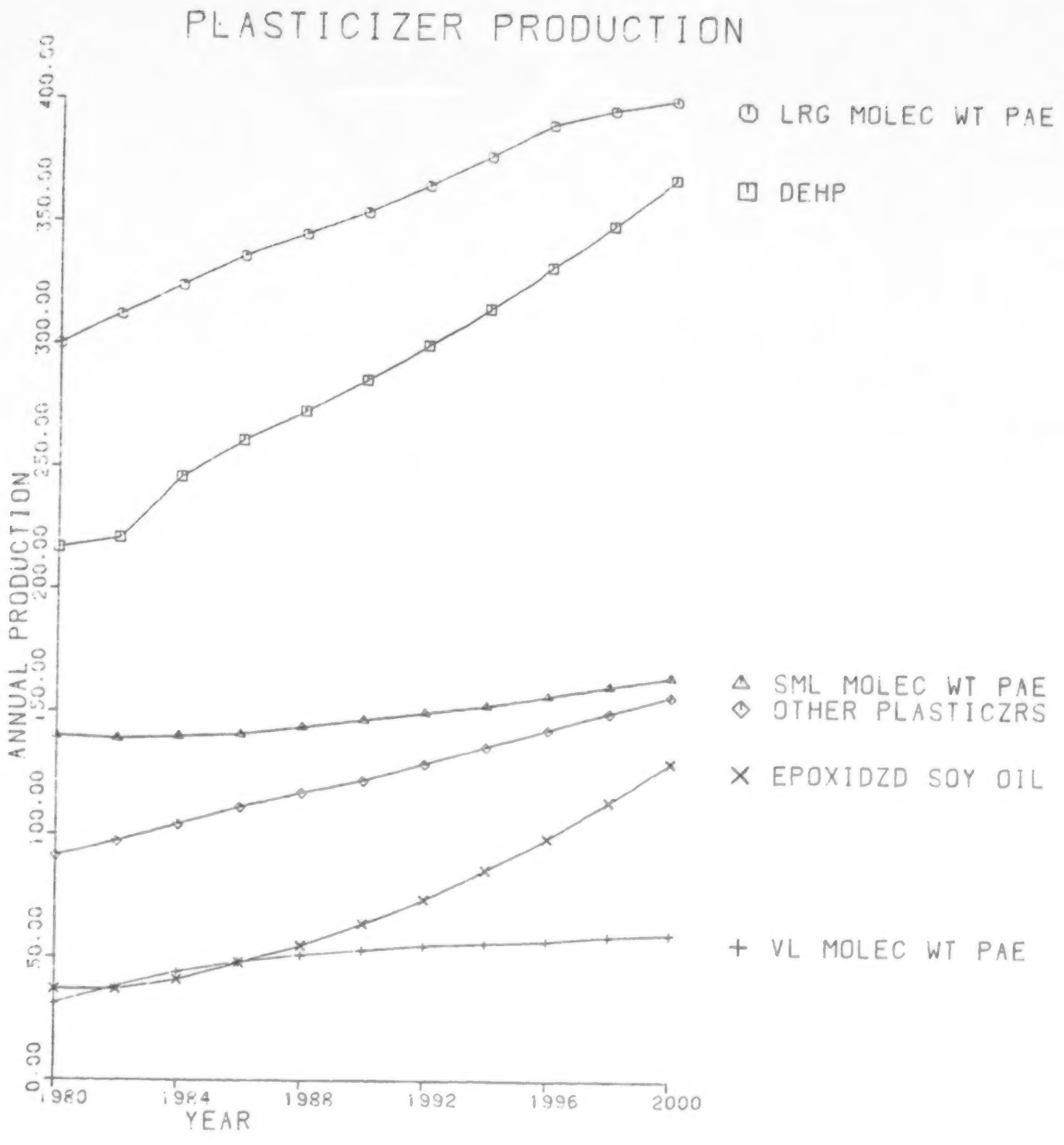
AVERAGE PRICES IN DOLLARS PER METRIC TON.



Quantities in Millions of Metric Tons

DECISION FOCUS INCORPORATED

Figure 4-1. Base Case Plastics Production



Quantities in Thousands of Metric Tons

DECISION FOCUS INCORPORATED

Figure 4-2. Base Case Plasticizer Production

Table 4-3

BASE CASE AVERAGE PLASTICS PRICES BY END-USE CATEGORY

REPORT # 13

AVERAGE PLASTICS PRICES

AF= AVERAGE PRICE GSS= PRICES		PLASTICS FOOD USES	MEDICAL SUPPLIES	AUTO USES	CONSUMER PRODUCTS	OTHER DEMAND
TIME		1	2	3	4	5
1978	1	818.03	852.16	841.00	817.07	811.08
1980	2	954.31	955.17	941.81	944.19	940.52
1982	3	988.77	988.54	973.85	978.13	974.28
1984	4	1026.21	1025.74	1009.98	1015.06	1010.89
1986	5	1062.05	1061.81	1045.09	1050.42	1045.93
1988	6	1093.87	1096.22	1078.67	1082.47	1077.25
1990	7	1128.56	1133.04	1114.78	1117.32	1111.34
1992	8	1159.93	1164.28	1145.45	1148.30	1141.95
1994	9	1192.77	1196.81	1177.57	1180.78	1174.04
1996	10	1226.16	1229.66	1210.15	1213.82	1206.70
1998	11	1256.91	1260.70	1241.01	1244.50	1236.85
2000	12	1288.36	1291.84	1272.25	1275.90	1267.77

PRICES IN DOLLARS PER METRIC TON.

Table 4-4

PLASTICIZER AND PLASTICS PRICES
(cents per pound)

Material	1980	1990	2000
DEHP	45	57	67
Large Molecular Weight Phthalate Esters	46	58	69
Small Molecular Weight Phthalate Esters	48	59	68
Very Large Molecular Weight Phthlate Esters	51	63	75
Epoxidized Soy Oil	65	74	82
Other Plasticizers	53	65	77
PVC with DEHP	41	49	56
Regular Grade PVC	42	50	57
Low Migration PVC	45	52	59
PE Plastics	42	50	57
Other Plastics	45	54	63

Table 4-5

BASE CASE PLASTICS USAGE BY END-USE CATEGORY

REPORT # 3

FOOD PACKAGING AND CONTAINERS

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC	 PE PLASTIC	 OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	59.14	61.11	65.05	837.75	481.95
1980	2	66.75	62.63	81.33	863.48	492.35
1982	3	73.21	65.10	96.42	902.06	503.82
1984	4	79.11	68.21	110.00	951.21	516.81
1986	5	84.71	71.72	122.07	1007.18	531.23
1988	6	89.56	75.02	132.06	1070.39	548.23
1990	7	94.07	78.29	140.94	1139.17	566.78
1992	8	99.19	82.20	150.31	1212.04	586.17
1994	9	104.79	86.60	160.29	1288.94	606.35
1996	10	110.79	91.39	171.03	1369.88	627.53
1998	11	116.94	96.36	182.24	1456.04	650.42
2000	12	123.30	101.56	194.27	1547.33	674.67

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 4

MEDICAL SUPPLIES

AF= SUM GSS= QUANTITY		MATERIALS PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC
TIME		1	2	3
1978	1	7.46	9.95	16.59
1980	2	7.38	8.57	21.05
1982	3	7.46	7.78	25.14
1984	4	7.70	7.42	29.03
1986	5	8.10	7.38	32.84
1988	6	8.64	7.59	36.70
1990	7	9.30	7.96	40.71
1992	8	10.07	8.49	44.98
1994	9	10.94	9.13	49.60
1996	10	11.90	9.87	54.62
1998	11	12.95	10.70	60.13
2000	12	14.09	11.62	66.20

QUANTITIES IN THOUSANDS OF METRIC TONS.

Table 4-6

BASE CASE PLASTICS USAGE BY END-USE CATEGORY

```
REPORT #  5

AUTOMOBILE USES

                                       MATERIAL
                          +-----------+-----------+-----------+
AF=  SUM                  | PVC WITH  | REGULAR   | LOW MIG.  |
GSS= QUANTITY             | DEHP      | PVC       | PVC       |
--------------------------+-----------+-----------+-----------+
TIME                      |     1     |     2     |     3     |
--------------------+-----+-----------+-----------+-----------+
1978                |   1 |     65.70 |     66.65 |     66.65 |
1980                |   2 |     73.39 |     68.53 |     74.72 |
1982                |   3 |     80.58 |     71.64 |     84.23 |
1984                |   4 |     88.06 |     75.99 |     94.59 |
1986                |   5 |     96.15 |     81.46 |    105.50 |
1988                |   6 |    105.04 |     87.99 |    117.04 |
1990                |   7 |    114.76 |     95.47 |    129.39 |
1992                |   8 |    125.53 |    103.96 |    142.75 |
1994                |   9 |    137.33 |    113.39 |    157.39 |
1996                |  10 |    150.19 |    123.77 |    173.51 |
1998                |  11 |    164.22 |    135.16 |    191.39 |
2000                |  12 |    179.44 |    147.60 |    211.32 |

QUANTITIES THOUSANDS OF METRIC TONS.
```

```
REPORT #  6

   OTHER CONSUMER PRODUCTS

                                            MATERIAL
                          +-----------+-----------+-----------+-----------+
AF=  SUM                  | PVC WITH  | REGULAR   | PE        | OTHER     |
GSS= QUANTITY             | DEHP      | PVC       | PLASTIC   | PLASTICS  |
--------------------------+-----------+-----------+-----------+-----------+
TIME                      |     1     |     2     |     3     |     4     |
--------------------+-----+-----------+-----------+-----------+-----------+
1978                |   1 |    288.88 |    517.10 |    827.57 |    493.46 |
1980                |   2 |    307.04 |    530.54 |    877.48 |    501.95 |
1982                |   3 |    325.80 |    552.03 |    932.90 |    512.50 |
1984                |   4 |    345.45 |    578.87 |    994.26 |    525.03 |
1986                |   5 |    365.80 |    608.94 |   1059.46 |    539.22 |
1988                |   6 |    384.92 |    638.23 |   1132.31 |    557.14 |
1990                |   7 |    403.72 |    667.78 |   1210.91 |    577.23 |
1992                |   8 |    425.18 |    702.02 |   1291.55 |    597.53 |
1994                |   9 |    448.68 |    739.90 |   1375.16 |    618.21 |
1996                |  10 |    473.99 |    780.95 |   1462.29 |    639.91 |
1998                |  11 |    500.30 |    823.85 |   1555.45 |    663.53 |
2000                |  12 |    527.75 |    868.93 |   1654.55 |    688.79 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

year 2000. This reflects an increased willingness by the uses of plastics products to pay a premium for low volatility, particularly in the key markets for food packaging, medical supplies, and automobile interiors.

As indicated in Table 4-4, PVC with DEHP retains a small price advantage over regular PVC with other plasticizers, due to the slightly lower costs of DEHP [15,4]. Polypropylene and polystyrene, aggregrated as "other plastics," show a somewhat greater percentage increase in price over time. This results from the larger requirements for fossil-based feedstocks.

In the plasticizer sector, the greatest percentage increase is in the quantity of epoxidized soy oil used, followed by that of the very large molecular weight phthalate esters. The relative price premium for epoxidized soy oil decreases over time due to its being produced in part from a renewable resource.

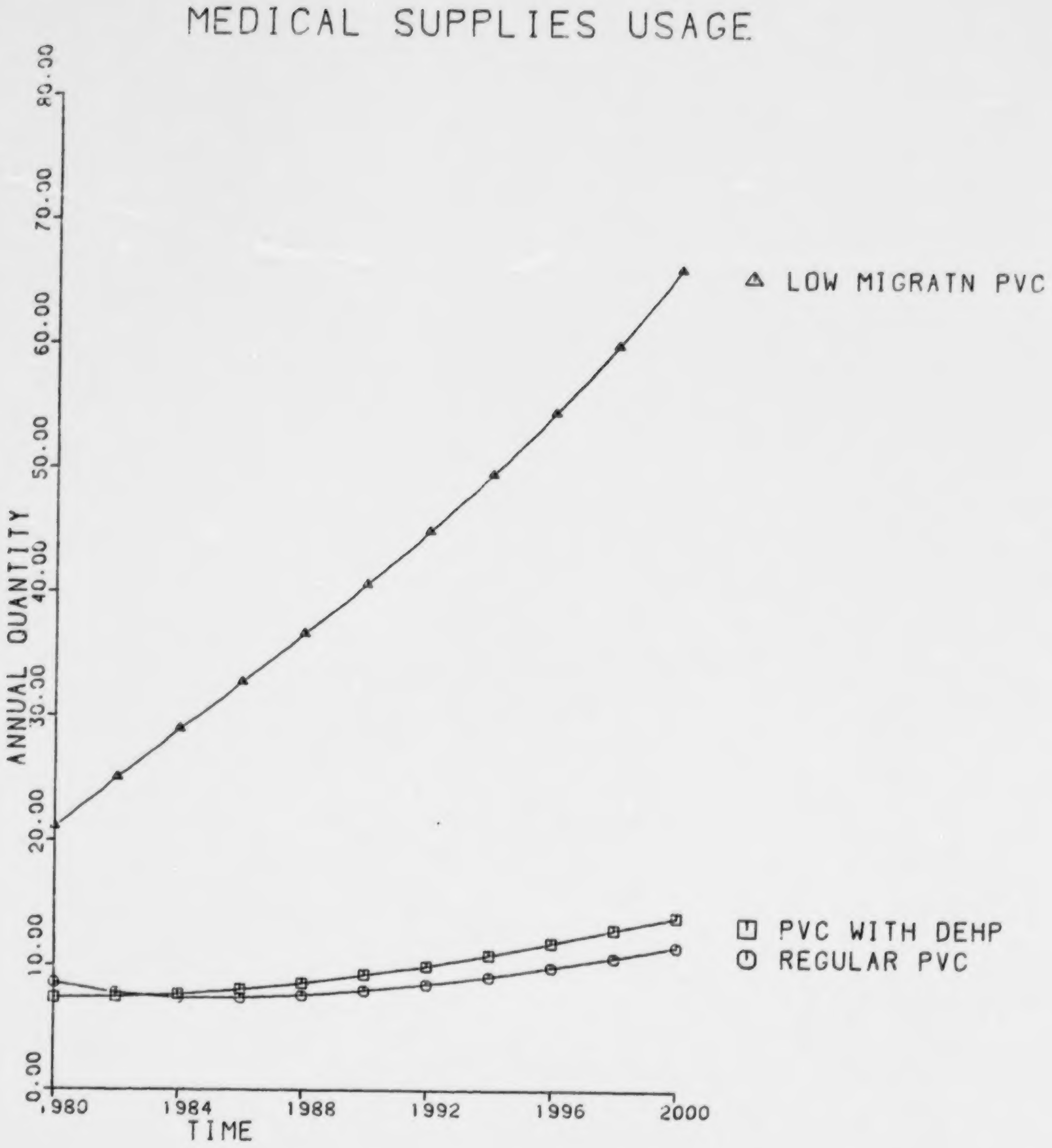
In the detailed breakdown of plastics usage shown in Tables 4-5 and 4-6, the general trends are an increase in the use of low migration PVC and a decrease in the market share for PP and PS (other plastics). The medical supplies and automobile markets show dramatic increases in the use of low migration PVC. This trend is shown clearly in Figure 4-3.

The model can provide economic information beyond market equilibrium prices and quantities. Required additions to production capacity (that is, the capacity of new plants built to serve changing demands) can be of considerable importance in assessing economic impacts. As an example, the estimates of required new capacity for DEHP are summarized in Table 4-7; these reflect economic decisions modeled in the DEHP conversion process model.

Of perhaps greater interest than the absolute results from the base case are the relative changes observed when trying several alternative regulatory policies. These are discussed in the next subsection.

REGULATORY POLICY RUN RESULTS

The implications of two different regulatory policies were examined using the prototype model. These cases were:



Quantities in Thousands of Metric Tons

DECISION FOCUS INCORPORATED

Figure 4-3. Base Case Plastics Demand for Medical Supplies

379

Table 4-7

NEW PLANT CAPACITY FOR DEHP IN THE BASE CASE
(Capacity in 1000s of metric tons per year)

1980	106
1982	76
1984	69
1986	67
1988	62
1990	59
1992	66
1994	72
1996	78
1998	84
2000	100

1. All production and use of DEHP is prohibited (the "prohibit" case).

2. The use of PVC with DEHP for medical supplies or in automobile interiors is prohibited (the "restrict" case).

The two policy cases together with the "no action" base case form the three regulatory decision alternatives discussed earlier in this section.

A key goal of the plastics industry economic model was to estimate the economic cost of each regulatory alternative. The primary measure we use to define the cost is the change in consumers surplus. Consumers surplus is a widely accepted method of estimating economic benefits to consumers [21,22]. When a regulatory action causes consumers surplus to decrease, the net change is a cost to consumers.*

Suppose some action causes the price of a good to increase. Not only will consumers pay more for each unit (for example, an automobile seat cover), but in the aggregate they will purchase fewer units due to the higher price. A good approximation to the loss in consumers surplus (and thus the net cost to consumers) is given by

$$\text{CCS} = (\text{New Price} - \text{Old Price}) * \frac{\text{New Quantity} + \text{Old Quantity}}{2}$$

where

CCS = change in consumers surplus

Old Price = product price without regulatory action

Old Quantity = quantity purchased given no regulatory action

New Price = product price given the effects of a regulatory action.

New Quantity = quantity purchased given the effects of a regulatory action (e.g., given the new price)

---

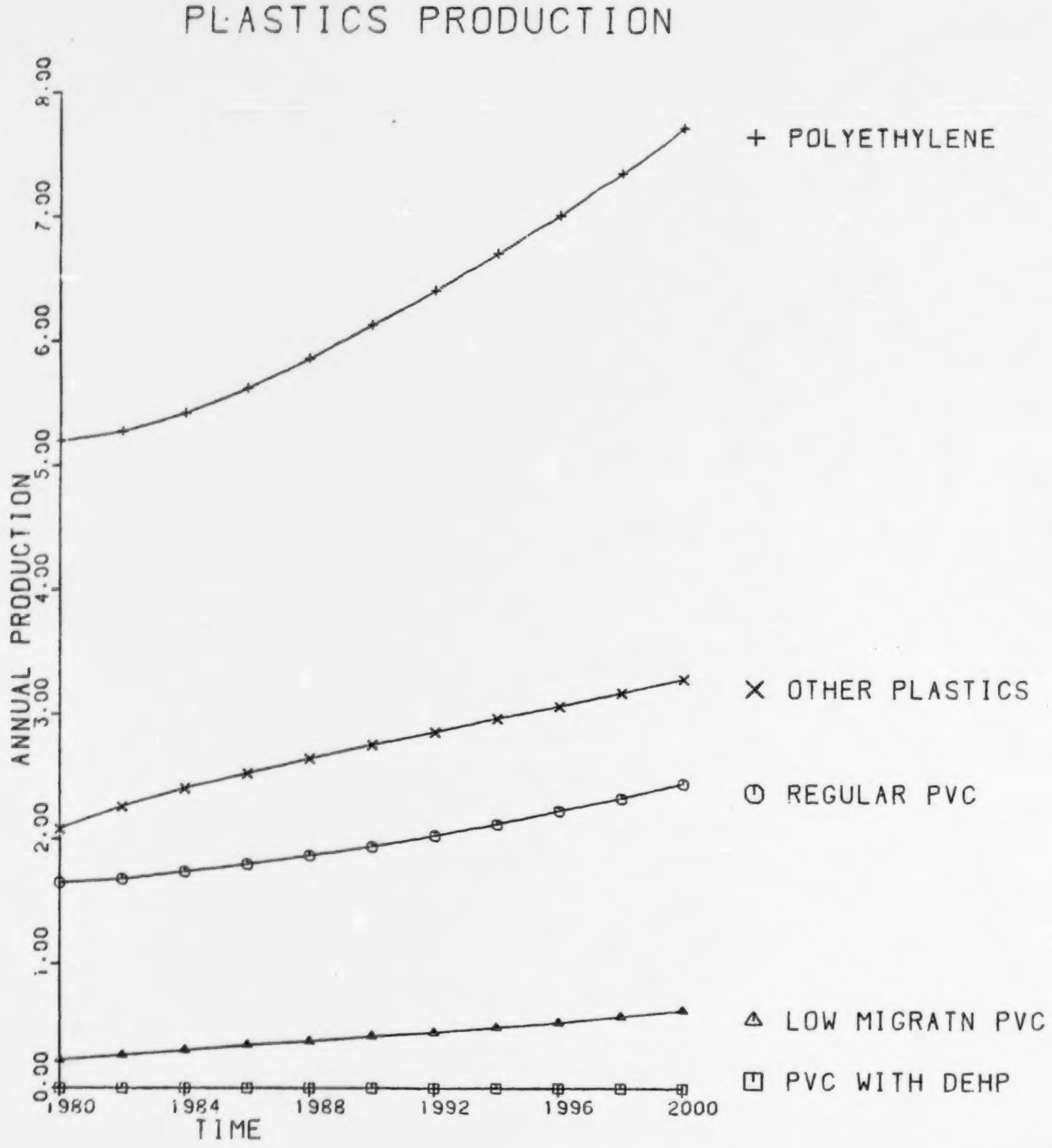
*This measure only reflects costs to consumers. Costs may also be borne by producers, and such costs should be addressed in a full-scale regulatory decision analysis.

The consumers surplus measure thus takes into account the two ways in which consumers (as a group) bear the impact of a regulatory action. They may have to pay more for a product whose intrinsic value has not increased, and they will tend to purchase a smaller amount of a product whose price has increased. It should be noted that in this section we are addressing only the economic costs of a regulatory action. No implication is intended with regard to the net worth of such an action after health benefits and other outcomes are balanced with economic costs.

The first policy examined is that of a full ban on the manufacturing and use of DEHP and PVC with DEHP starting in 1982. The qualitative effects are shown in Figures 4-4 and 4-5. These can be contrasted with Figures 4-1 and 4-2, which summarized the base case (note that the scales are different). As may be expected, the market share of DEHP is taken over primarily by other large and small phthalate ester plasticizers. The use of more specialized plasticizers such as epoxidized soy oil does not change significantly. The quantities of regular PVC and other plastics have increased, taking the place of the PVC with DEHP. The short-run response to a ban on DEHP is relatively smooth. This is consistent with an assumption that shifting between producing different types of plastics and plasticizers is relatively straightforward. To the extent that this assumption is not true, the short-run effects, especially on prices, may exceed those estimated by the prototype model.

The full set of quantitative results for the "prohibit" case are included in Appendix B. The effect on plastics prices to end users ranges from an increase of about one-half of a percent for the "other demand" category in 1982 to about one and one-half percent for automobile uses in the year 2000. This corresponds to price increases of less than one cent per pound. The impact is greatest on the food packaging, medical supplies, and automobile markets, as these currently use the greatest fraction of PVC with DEHP.

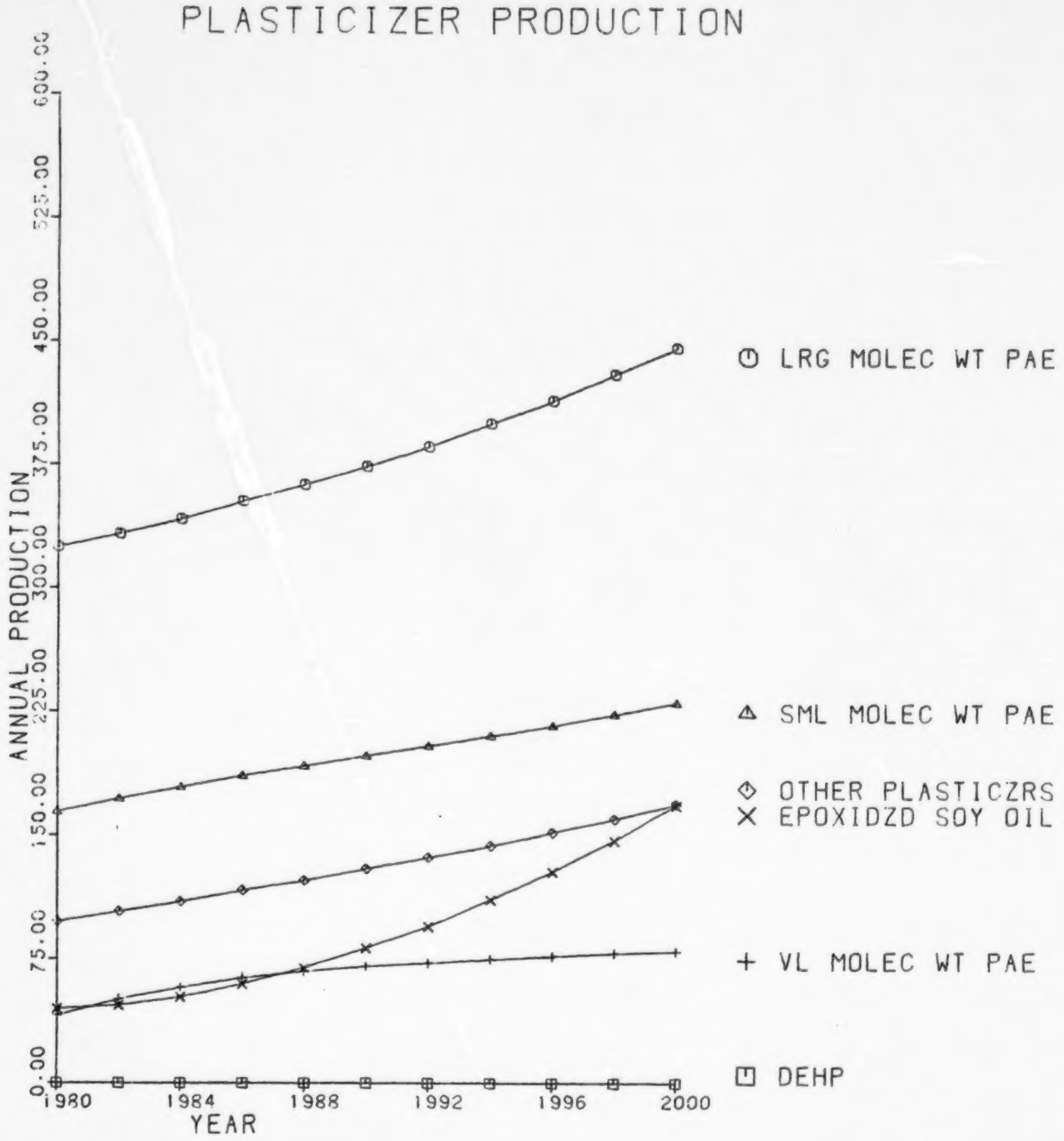
The net cost to consumers was calculated for each market using the formula discussed above. The net cost summed over all markets is shown in Table 4-8. The total cost to the economy is probably greater than shown in the near term due to conversion and shutdown costs incurred by industry.



Quantities in Millions of Metric Tons

DECISION FOCUS INCORPORATED

Figure 4-4. Plastics Production with "Prohibit" Policy



Quantities in Thousands of Metric Tons

DECISION FOCUS INCORPORATED

Figure 4-5. Plasticizer Production with "Prohibit" Policy

Table 4-8

COSTS TO CONSUMERS

(measured by change in consumers surplus,
in millions of 1978 dollars)

Year	Prohibit DEHP	Restrict DEHP
1982	54.2	2.6
1984	76.8	2.7
1986	80.7	2.8
1988	90.7	3.1
1990	101.4	3.4
1992	114.4	3.8
1994	124.0	4.3
1996	142.8	4.8
1998	157.0	5.3
2000	171.3	5.9

In the longer term, the prototype model may overestimate costs as it does not currently reflect innovation or technological change stimulated by a regulatory action (it would be straightforward to examine such effects in a refinement of the model). On the whole, we believe that the net cost to the economy of a complete ban on DEHP would on the order of 100 million dollars per year.

The second policy tested would prohibit the use of PVC with DEHP for medical supplies or automobile interiors, two categories with relatively large opportunities for human exposure to DEHP. The prototype model suggests that such an action would have no significant effects on other uses for plastics. Average plastics prices for medical and automobile uses would increase on the order of one percent. Complete results are included in Appendix B.

The net cost to consumers, summarized in Table 4-8, would increase from about 2.6 million dollars in 1982 to 5.9 million dollars in 2000. As with the prohibit policy discussed earlier, the effects may be underestimated in the near term and overestimated in the long term, with the net cost being on the order of three or four million dollars per year. This is considerably less than the cost of the complete ban on DEHP, due to the relatively small quantities used in the affected markets.

In addition, we examined a case that included the restrictions on the use of DEHP discussed above, plus a limit constraining the production of PVC with DEHP to not significantly exceed the 1980 level (roughly 800 thousand metric tons). This case was not carried to the point of computing changes in consumers surplus, but serves to demonstrate the capability of the modeling approach to investigate the impact of production constraints. The results (also included in Appendix B) show an economic impact falling between the two policy cases just discussed. Plastics prices increase in all market segments, but never by more than about three-fourths of a percent. In the near term, the limit on DEHP production has little effect, while in the long term, the markets have adjusted with other products replacing the loss of PVC with DEHP. The changes in consumers surplus would fall between the prohibit and restrict cases.

SENSITIVITY ANALYSIS RESULTS

Plastic resins and plasticizers are produced in large part using feedstocks derived from fossil fuels. The future prices of such fuels, and thus of the chemical feedstocks, are the source of considerable uncertainty. In order to investigate the sensitivity of the plastics industry and potential regulatory actions to such uncertainty, we developed test cases with higher and lower feedstock price forecasts, as compared to the base case.

Price forecasts used in the sensitivity tests are shown in Table 4-9. As the production of chlorine (a major input to PVC production) is highly energy-intensive, its prices were adjusted as well. In the base case the price of fossil feedstocks increases by an average of 3.1 percent per year, while chlorine shows an average 2.5 percent increase. The "higher prices" sensitivity case has an average annual increase of six percent for fossil

Table 4-9

SENSITIVITY TEST FEEDSTOCK PRICES
(all prices in 1978 dollars per metric ton)

Higher Prices Case

Year	Fossil Liquids	Chlorine
1978	172	294
1980	265	312
1982	298	337
1984	335	365
1986	376	395
1988	422	427
1990	475	462
1992	533	500
1994	599	540
1996	673	584
1998	756	632
2000	850	684

Lower Prices Case

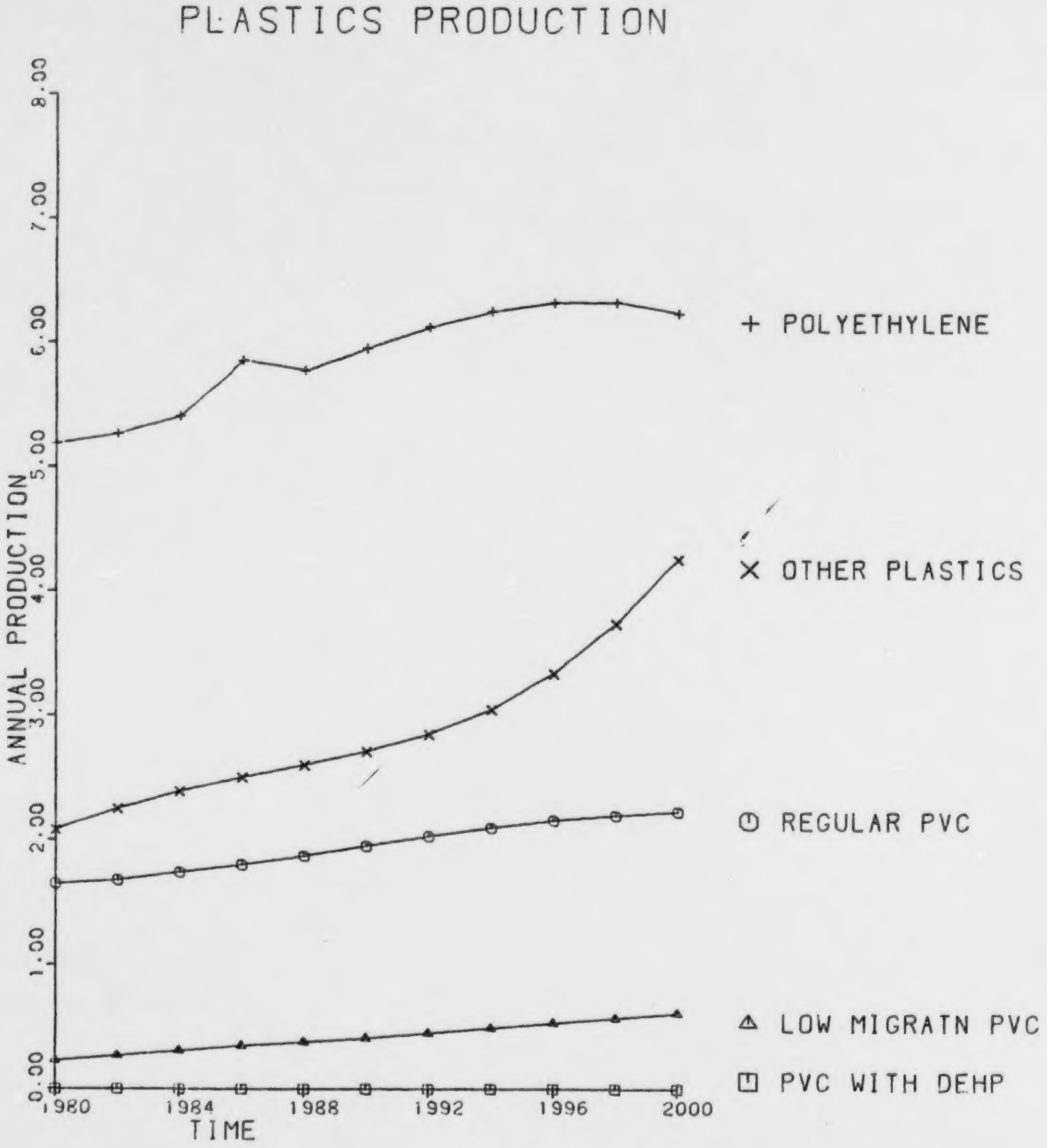
Year	Fossil Liquids	Chlorine
1978	172	294
1980	265	312
1982	270	318
1984	276	325
1986	281	331
1988	287	338
1990	293	345
1992	299	352
1994	305	359
1996	311	366
1998	317	373
2000	323	381

liquids and four percent for chlorine. The "lower prices" case uses one percent annual increases for both feedstocks.

Four test cases were run. These were the high and low price forecasts with no regulatory action (the base case), and the high and low price forecasts with a full ban on DEHP (the prohibit case). Complete results for the four sensitivity cases are included in Appendix B. The impact on plasticizer and plastic production for the case with high feedstock prices and a ban on DEHP is summarized in Figures 4-6 and 4-7. These figures can be compared to Figures 4-4 and 4-5, which show analogous results for the prohibit case with nominal feedstock prices. The use of polyethylene, which uses relatively more fossil derived feedstocks per ton of plastic, increases less rapidly (given high feedstock prices) and peaks around 1995. The "other plastics" (polypropylene and polystyrene) increase their market share significantly. In the plasticizer sector large molecular weight phthalate esters lose market share and the use of small phthalate esters increases less rapidly, while the demand for epoxidized soy oil increases dramatically. The soy oil, based in large part on a renewable resource, incurs a considerably smaller price increase resulting from the higher fossil feedstock prices.

An interesting observation is that the net economic impact of banning DEHP is actually slightly less under the high feedstock scenario than it is with nominal feedstock prices. This is probably due to the somewhat smaller market shares for DEHP and PVC with DEHP when feedstock prices are greater. The plastics prices increases are never more than two-thirds of a cent per pound, or less than one-half of one percent. The overall cost to consumers of a DEHP ban is still on the order of 50 to 100 million dollars annually. Under the low feedstock price scenario, the economic cost of the prohibit action is very close to that incurred in with nominal feedstock prices.

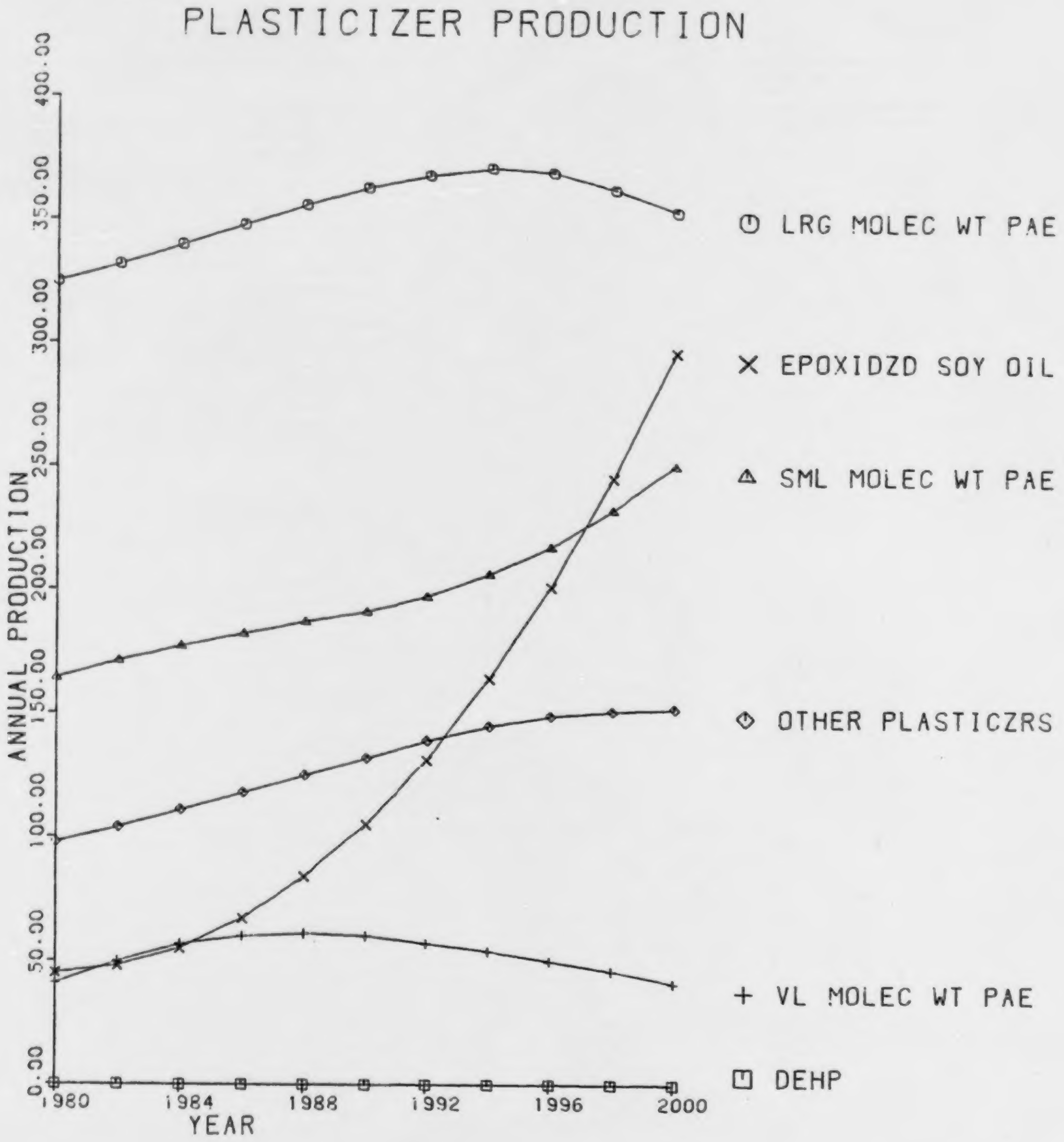
The overall impact of the uncertainty in feedstock prices on a regulatory decision depends on health effects and other factors in addition to the economic costs. In this case study, we are only demonstrating the use of the prototype economic model to analyze the sensitivity of economic impacts to such uncertainties.



Quantities in Millions of Metric Tons

DECISION FOCUS INCORPORATED

Figure 4-6. Plastics Production with High Feedstock Prices and "Prohibit" Policy



Quantities in Thousands of Metric Tons

DECISION FOCUS INCORPORATED

Figure 4-7. Plasticizer Production with High Feedstock Prices and "Prohibit" Policy

Section 5

POTENTIAL DEVELOPMENT AND USE OF THE ECONOMIC ANALYSIS MODEL

ADDITIONAL POLICY AND SENSITIVITY ANALYSIS

The prototype plastics industry model would be useful in the analysis of a wide range of potential regulatory actions concerning DEHP, other plasticizers, and PVC. First-order quantitative estimates of the economic implications of policies including use restrictions, production controls, and modifications to production processes could be determined. Regulatory actions that impose costs on producers but do not directly limit or restrict production on use could also be examined. This could include, for example, rules mandating the use of certain health and safety protection equipment or procedures in plants using DEHP.

The current model can be used to assess secondary economic impacts such as plant closings or reduced economic growth in the plastics industry. Estimates of plant closings can be derived from the changes in productive capacity calculated by the model. Effects on employment can be inferred from production quantities and manufacturing and from capacity, both of which are standard model outputs.

Section 4 discusses an example sensitivity analysis on feedstock prices using the prototype model. Sensitivity analyses could be carried out on a wide range of other data, including demand growth rates, process economics parameters such as capital costs, financial parameters including interest rates, and market behavior parameters. Such sensitivity analysis could be used in a full regulatory decision analysis to determine to which uncertainties the decision is most sensitive. The important uncertainties could then be factored explicitly into the analysis, as discussed in Part I, Section 3.

The results of policy and sensitivity analyses using a model of plastics industry economic market behavior such as our prototype model can then be used as inputs to other models in a more extensive regulatory analysis. Production quantities and manufacturing capacity may be key inputs to human exposure and environmental fate models, for example.

FURTHER DEVELOPMENT OF THE PROTOTYPE MODEL

The prototype model is sufficient to provide a good estimate of the quantitative economic impact of regulatory actions. In particular, it can help screen potential actions to determine which ones merit further study. To determine the economic effects of particular actions in greater detail and with more accuracy, it would be necessary to extend the prototype model.

It would be straightforward to add greater detail to the model in key sectors or to model in more detail the links or pathways between the sectors. For example, the manufacturing of specific plastics products, such as automobile seat covers, blood bags, plastic cups, or plastic wrap, could be modeled explicitly. This would be implemented as an additional set of conversion processes placed between the plastics production stage and the end-use demands. Such detail would allow further disaggregation of important market sectors to identify economic impacts more precisely.

If process economics and the details of resin or plasticizer production were critical to a regulatory decision, the model could be expanded to provide more resolution in such areas. The production of DEHP could, for example, be represented by a full set of conversion process models, one for each stage in the sequence from chemical feedstocks to the plasticizer compound.

As a final example, the feedstock sector--and particularly the uncertainties in price and product availability--could be highly important to the regulatory decisions. Our assumption for the prototype model of a generic fossil liquid feedstock could easily be relaxed, with each relevant feedstock (such as ethane, propane, and BTX) represented explicitly. The production of these feedstocks from fossil resources such as crude oil or natural gas could also be added to the model.

SUMMARY

The prototype plastics industry model is potentially useful for a wide variety of regulatory policy sensitivity analyses. It provides a firm basis for further development of a more detailed model. The GEMS and MDMS software makes adding detail or otherwise modifying the model or data base a reasonably easy task. Any further model use and development should be guided by the needs of a regulatory analysis, focusing model detail and analytical effort on key issues in the regulatory decision.

Section 6

REFERENCES

[1] National Cancer Institute, "Carcinogenesis Bioassay of Di-(2-Ethylhexyl) Phthalate (Draft Report)," DHHS Publication No. (NIH) 81-1773 (1980).

[2] Chemical and Engineering News, February 22, 1982.

[3] "Plasticizers," Modern Plastics (September 1979).

[4] Synthetic Organic Chemicals: U.S. Production and Sales, 1977 and 1979, U.S. International Trade Commission, Publication 1099.

[5] Encyclopedia of Polymer Science and Technology (New York: John Wiley and Sons, 1969), S.v. "Acids and Derivatives, Aromatic," and "Plasticizers."

[6] L. I. Nass, Encyclopedia of PVC (New York: Marcel Dekker, 1976), Chapter 11.

[7] J. Frados, ed., Plastics Engineering Handbook (New York: Van Nostrand Reinhold, 1976), pp. 365-367, 842-843.

[8] Chemical Technology: An Encyclopedia Treatment (New York: Barnes and Noble, 1973), Vol. VI, S.v. "Polyvinyl Chloride (PVC)."

[9] R. L. Gosselin et al., Clinical Toxicology of Commercial Products (Baltimore: The Williams and Wilikins Company, 1974), pp. 137-138.

[10] E. G. Cazalet, Generalized Equilibrium Modeling: The Methodology of the SRI-Gulf Energy Model. Final report prepared by Decision Focus Incorporated for the Federal Energy Administration (1977).

[11] R. J. Adler et al., The DFI Generalized Equilibrium Modeling System (Palo Alto, Calif.: Decision Focus Incorporated, 1979).

[12] R. A. Flint et al., Users Guide to the DFI Model Data Management System (MDMS), Decision Focus Incorporated (1980).

[13] C. E. Clark, Jr., et al., Modeler's Guide to Building Generalized Equilibrium Models, Decision Focus Incorporated (1979).

[14] Chemical Economics Handbook, SRI International (1980 and preceding years).

[15] "Special Reports on Materials 1980," and "In Plasticizers, Less Means More," Modern Plastics (January 1980, December 1979).

[16] Process Economics Handbook, SRI International (1980 and preceding years).

[17] Agricultural Statistics 1978, U.S. Government Printing Office.

[18] Annual Report to Congress 1979, Volume Three: Projections, U.S. Department of Energy, Energy Information Agency. Publication DOE/EIA-0173(79)/3 (1979).

[19] S. M. Barrager et al., Integrated Models for R&D Planning, Electric Power Research Institute (1980). EA-1462.

[20] S. Salant, "Exhaustible Resources and Industrial Structure," Journal of Political Economy 84, no. 5 (1976).

[21] R. D. Willig, "Consumer's Surplus Without Apology," The American Economic Review 66, no. 4 (1976).

[22] D. M. Nesbitt et al., An Analytical Framework for Assessing Federal R&D Strategies on Liquid and Gaseous Fuels. Final report prepared by Decision Focus Incorporated for U.S. Department of Energy (1980).

[23] "Data for the TVA Regional Energy-Economy Model," DFI project notes and memoranda (1978).

[24] Technical Assessment Guide, Electric Power Research Institute (1978).

[25] S. Salant, "Imperfect Competition in the International Energy Market: A Computerized Nash Cournot Model," ICF Incorporated (1979).

Appendix A

DATA FOR THE PROTOTYPE PLASTICS INDUSTRY MODEL

This appendix documents the sources and derivation of data used in the prototype economic model of the plastics industry. Data sources include government and industry publications, trade journals, results of other models, and previous work by Decision Focus. Most data require aggregation, conversion to different units, or some other adjustment.

Data for the prototype model can be thought of as falling into six categories:

1. Parameters describing the financial environment of the industries represented in the model.
2. Data describing the process economics of the modeled industries.
3. Parameters defining the nature of the economic markets in which the industries compete.
4. Demand information.
5. Feedstock price projections.
6. Initial estimates of quantities of materials demanded and supplied.

FINANCIAL PARAMETERS

Financial data are used in the model to calculate depreciation, interest, and other charges against capital stock, as well as tax effects [11,22]. We found no sources of data for financial parameters specific to the plastics industry. The parameters used, listed in Table A-1, were based on previous DFI experience in modeling a variety of industrial

Table A-1

FINANCIAL PARAMETERS

1. Real return on equity financing	0.10
2. Real return on debt financing	0.04
3. Income tax rate (including state)	0.52
4. Investment tax credit rate	0.10
5. Property tax rate (on capital stock)	0.02
6. Planning lead time (years)[1]	2.00
7. Plant lifetime (years)	30.00
8. Tax life (years)	11.00
9. Debt life (years)	20.00
10. Equity fraction[2]	0.75

---

[1] Average time required to construct new capacity after initial go-ahead.

[2] Fraction of new capacity financed by equity; remainder is debt financed.

sectors [22,23,24]. Some parameters, such as the property and income tax rates, are averages of values that vary from one state to another. We assumed, having no information to the contrary, that the same set of financial parameters applied to all industrial processes in the resin, plasticizer, and plastics sectors.

PROCESS ECONOMICS

Process economics parameters summarize the technology of converting one or more inputs to a primary output. The parameters include capital cost of new capacity (expressed as dollars per unit of capacity), variable operating costs, input-output coefficients, and plant availability.

Process economics parameters for industrial processes in the resin, plasticizer, and plastics industries were developed primarily from data in the Chemical Economics Handbook [14] and the Process Economics Handbook

[16]. Where data were unavailable, parameters used in the prototype model represent DFI estimates based on comparison with similar technologies.

The data used generally required several steps to derive the actual model parameters from the source data. Necessary adjustments included converting all costs and prices to a common basis (1978 dollars), aggregating several items to form one model parameter (e.g., adding labor, electricity, and secondary material inputs to get the variable operating cost), and combining a sequence of industrial processes or process steps into one overall industrial conversion process.

The raw data available in the Process and Chemical Economic Handbooks are broken down in varying, and often considerable, degrees of detail. The data for the production of 2-ethylhexanol (a factor in the production of di-ethylhexyl phthalate plasticizer) are provided in Table A-2 as an example (from [16]). The data are provided for a base size plant (120 million pounds per year in the example). The SRI process economics cost index is used to adjust to common year dollars.

To maintain consistency, a set of standard assumptions was used in converting the raw data to a form appropriate for the prototype model. Process economics parameters required by the model for each industrial process are specific capital cost (SCC), variable operating cost (VOC), input-output coefficient(s) (I/O), and plant availability (or stream factor).

The assumptions used are as follows:

1. All costs are converted to 1978 dollars using the cost indexes provided [14,16]. The index for 1978 is 275; the index corresponding to the data in Table A-2 is 268. Therefore, all costs in the 2-ethylhexanol example were multiplied by 275/268.

2. Total plant cost is assumed to include site, working capital, and start-up costs. It was adjusted, if necessary, to deduct interest charges on capital used during plant construction, as this is calculated by the model. The total cost was divided by plant capacity and adjusted by the cost index to provide the specific capital cost. When necessary, the SCC in dollars per pound was multiplied by 2200 to convert to dollars per metric ton. For 2-ethylhexanol, we have $33.8 million divided by 120 million pounds per year times 275/268 times 2200 equals $636 per metric ton capacity.

Table A-2

PROCESS ECONOMICS DATA FOR 2-ETHYLHEXANOL

Cost data for plant with capacity of 120 million pounds per year. Data reported May 1979, cost index = 268, stream factor = 0.9.

	Plant Cost (millions)
Basic Plant	$18.03
Offsite Costs	3.93
General Services	4.39
Start-up	1.96
Working Capital	5.49
Total Plant Cost	$33.80

	Production Costs (cents/pound)
Labor	0.95
Other Materials	1.70
Maintenance	0.49
Utilities	1.35
Overhead	0.76
G&A	2.40
Depreciation	2.20
Interest on Working Capital	0.43
Byproduct Credits	-3.37

Input-Output Coefficients

Propylene	0.87	pounds/pound of output
Synthetic Gas	21.85	scf/pound of output

3. Variable operating cost is assumed to include labor, overhead on labor, secondary (or "other") material inputs, maintenance, utilities, G&A, and (when appropriate) a deduction for byproduct credits. The sum is converted to a dollars-per-metric-ton figure and adjusted to 1978 dollars. For our example, we have 4.3 cents per pound times 2200 divided by 100 (cents per dollar) times 275/268 equals $97 per metric ton. Depreciation and interest are calculated internally by the model (based on the SCC), and are not included in the VOC.

4. Input-output coefficients usually required no adjustment. However, in the prototype model, we have assumed a single generic fossil feedstock. In some cases, the feedstock input-output coefficient(s) required adjustment to maintain a consistent ratio of heat content to product price. In the 2-ethylhexanol example, 21.85 scf of synthetic gas is the Btu equivalent of 0.92 pounds of propylene. Added to the coefficient for propylene, this results in a net input-output coefficient for feedstock to product of 1.79.

Interest on capital invested in the plant is calculated by the model and included in the effective capital cost (ECC) discussed in Section 5.

Parameters for all necessary industrial processes were derived using these assumptions. The process economics parameters are summarized in Table A-3. All parameters are derived from data in [14] and [16] unless otherwise noted. The stream factor for all processes was 0.9.

As described in Section 5, in many cases we combined several processes to form the aggregate conversion (or production) process represented in the model. For example, the PVC resin process in the prototype model represents the composition of VC monomer production and a polymerization stage, resulting in PVC resin. A detailed example, for di-ethylhexyl phthalate, was discussed in Section 5. In each case, to fully reflect the process economics of all steps in the production of a material or compound, the SCC and VOC of the earlier stages are multiplied by the input-output coefficient(s) at the next stage and summed over all stages. Final input-output coefficients are the product of all intermediate steps. The derivation of the final process economics parameters are summarized in Tables A-4(a) through A-4(g). Notes regarding special cases and assumptions are included in the tables.

Table A-3

PROCESS ECONOMICS PARAMETERS FOR INDIVIDUAL INDUSTRIAL PRODUCTION PROCESSES

Product	SCC ($/metric ton/year)	VOC ($/metric ton)	Feedstock	I/O Coefficient
Ethylene/propylene	$ 363	$ 58	Ethane/propane mix	1.40
2-Ethylhexonal	636	97	Ethylene	1.79
Phthalic Anhydride	407	96	O-xylene	1.02
O-xylene	132	37	BTX	1.12
Di-ethylhexyl Phthalate	137	71	2-Ethylhexanol Phthalic Anhydride	0.69 0.39
Adipic Acid	1200	300	Fossil Liquids	4.70
Di-ethylhexyl Adipate	384	209	Adipic Acid 2-EH	0.41 0.72
Epoxidized Soy Oil	271	213	Soy Oil H_2O_2	0.93 0.37
Large Alcohols	449	150	Fossil Liquids	1.92
Vinyl Chloride Monomer	240	163	Ethane Chlorine	0.53 0.59
VC Polymerization	564	136	VC Monomer	1.03
Polyethylene Resin	1100	250	Fossil Liquids	1.82
Polystyrene Resin	900	200	Fossil Liquids	3.12
PVC Plastic (from resin)[1]	100	50	PVC Plasticizer	0.77 0.28
Polyethylene Plastic (from resin)[1]	100	50	PE Resin	1.03
Other Plastics[1]	100	50	Resin Plasticizer	0.98 0.07

---

1. Plastic process parameters are inferred from information in Modern Plastics, a trade journal [16]. "Other Plastics" is an average of polypropylene and polystyrene. As little specific data was available, we assumed that capital and operating costs were the same for all three plastics formation processes.

Table A-4(a)

DERIVATION OF PROCESS ECONOMICS FOR DEHP

Stage	SCC	VOC	I/O
Ethylene	$ 363	$ 58	1.40
2-Ethylhexanol from ethylene	636	97	1.79
Net for 2-EH from feedstock	1286	201	2.51
O-xylene	132	37	1.12
Phthalate anhydride from o-xylene	407	96	1.02
Net for phthalate anhydride from feedstock	542	134	1.14
DEHP from 2-EH and phthalate anhydride	137	71	2-EH 0.69 P.A. 0.39
Net for DEHP from feedstock	1236	262	2.18

Table A-4(b)

DERIVATION OF PROCESS ECONOMICS FOR LARGE[1] MOLECULAR WEIGHT PHTHALATE ESTERS

Stage	SCC	VOC	I/O
Ethylene	$ 363	$ 58	1.40
Large alcohols from ethylene	543	124	1.85
Net for large alcohols	1215	231	2.59
Net for phthalate anhydride (see Table 4(a))	542	134	1.14
Phthalate esters from alcohols and P.A.	137	71	Alc. 0.69 P.A. 0.39
Net for large molecular weight phthalate esters	1187	283	2.23

---

[1] Large molecular weight phthalate esters were assumed to be those with molecular weights similar to DEHP.

Table A-4(c)

DERIVATION OF PROCESS ECONOMICS FOR VERY LARGE MOLECULAR WEIGHT PHTHALATE ESTERS

Stage	SCC	VOC	I/O
Ethylene	$ 363	$ 58	1.40
Very large molecular weight alcohols from ethylene	449	150	1.92
Net for very large molecular weight alcohols	1146	261	2.69
Net for phthalate anhydride (see Table 4(a))	542	134	1.14
Phthalate esters from alcohols and P.A.[1]	137	71	Alc. 0.77 P.A. 0.31
Net for very large molecular weight phthalate esters	1187	314	2.42

---

1. I/O coefficients for alcohol and P.A. were adjusted from detailed data for DEHP by the ratio of molecular weights (assuming average of 12 carbon size for very large molecular weight alcohols) and renormalized.

Table A-4(d)

DERIVATION OF PROCESS ECONOMICS FOR SMALL MOLECULAR WEIGHT PHTHALATE ESTERS

Stage	SCC	VOC	I/O
Ethylene	$ 363	$ 58	1.40
Small molecular weight alcohols from ethylene	600	150	1.80
Net for small molecular weight alcohols	1253	244	2.52
Phthalate anhydride (see Table 4(a))	542	134	1.14
Small molecular weight phthalate esters from alcohols and P.A.[1]	100	200	Alc. 0.54 P.A. 0.54
Net for small molecular weight phthalate esters	1069	410	1.98

---

1. I/O coefficients for alcohol and P.A. were adjusted from detailed data for DEHP by the ratio of molecular weights (assuming average size of four carbons for small alcohols) and renormalized. The process economics were assumed to be less capital intensive and more operating cost intensive due to smaller quantities being produced.

Table A-4(e)

DERIVATION OF PROCESS ECONOMICS FOR OTHER PRIMARY PLASTICIZERS[1]

Stage	SCC	VOC	I/O
Adipic acid	$1200	$300	0.48
2-Ethylhexanol (see Table 4(a))	1286	201	2.51
Di-2-ethylhexyl adipate from adipic acid and 2-EH	384	209	A.A. 0.41 2-EH 0.72
Net for Di-2-ethylhexyl adipate	1801	476	3.73

---

[1] Based on process economics for di-2-ethylhexyl adipate.

Table A-4(f)

DERIVATION OF PROCESS ECONOMICS FOR EPOXIDIZED SOY OIL

Stage	SCC	VOC	I/O
H_2O_2[1]	$1200	$300	4.50
Epoxidization	271	213	Soy 0.93 H_2O_2 0.37
Net for epoxidized soy oil	713	323	Soy 0.93 fossil 1.66

---

[1] The process economics parameters for H_2O_2 were chosen to calibrate with product cost data in [4].

Table A-4(g)

DERIVATION OF PROCESS ECONOMICS FOR PVC RESIN

Stage	SCC	VOC	I/O
VC Monomer	$240	$163	ethane 0.53 chlorine 0.59
Polymerization	564	136	1.025
Net for PVC Resin	810	303	ethane 0.54 chlorine 0.61

MARKET PARAMETERS

The models of economic markets (also known as allocation processes) used in the prototype plastics industry model are described by three types of parameters: the share price sensitivity, the behavioral lag, and the fractions of market share at equal product prices.

The market share price sensitivity is analogous to the standard economic idea of an elasticity. It defines the extent to which the market shares received by competing products, such as plasticizers, are determined by price differences. Large values for the share price sensitivity parameter imply that the market is highly sensitive to price. A good needs only a small edge in price to gain a very large share of the market. Conversely, low values of the price sensitivity parameter are used to model markets that respond less drastically to price differences. An extremely low value (close to zero) would imply that all competing products would get roughly similar market shares, regardless of price.

A moderately high share price sensitivity parameter value of 10.0 was used for all end-use markets (food wrapping and packaging, medical supplies, automobile interiors, consumer products, and other) and for plasticizer input factor markets to PVC plastics production processes. Thus, we have assumed these markets to be relatively sensitive to prices. A moderate parameter value of 5.0 was used for all other markets in the prototype model, reflecting an assumption of somewhat reduced sensitivity to small changes in price.

The behavioral lag parameter defines the average number of years it takes for a potential change in market shares induced by a change in prices to actually be realized in the marketplace. This reflects the fact that price changes do not result in immediate changes in demand patterns. Consumer buying patterns, inventories, long lead times for capital equipment, and other effects contribute to this lag. The average lag was assumed to be two years in all end-use demand markets and in all markets for plasticizers as input factors to PVC production. The average lag in the material input market for "other resins" was assumed to be four years. An average lag of three years was used in all other markets in the prototype model.

These values are based on DFI experience with models of similar industrial sectors [22,23] and on qualitative descriptions in trade journals of the plastics industry [15].

The market share fractions at equal product price parameters are used as a first-order method of modeling products that compete on the basis of characteristics other than price. For example, plasticizers compete on the basis of ease of use, plasticizing efficiency, and volatility, as well as price. The fractions at equal price parameters define the market shares that each product would receive were they all at the same price (the default, for homogenous goods, is equal shares). The parameters used (as summarized in Table A-5) were selected so as to calibrate market shares to estimates of initial quantities in the relevant markets.

INITIAL QUANTITY ESTIMATES

The GEMS modeling approach [10] used to develop the prototype model solves for market equilibrium prices and quantities such that supply and demand are in balance. The solution algorithm requires that initial estimates of equilibrium quantities be provided.

Estimates of the quantities of flexible plastics used in 1978 were developed from data in Modern Plastics [15] and checked against data in the Chemical Economics Handbook [14]. The estimates are summarized at the top of Table A-6. Food packaging and wrapping is assumed to include bags, food wrap, bottles, eating utensils and containers, closures, food tubs, and packaging for drugs and personal care items. Medical supplies primarily include blood bags and tubing. Automobile interior uses are dominated by upholstery and seat covers but include mats, liners, and trim. The consumer products category includes all non-food- or drug-related consumer uses: housewares, toys, trash bags, clothing, recreation goods, hoses, flooring, and furniture. The "other" flexible plastics demand is composed of flexible pipe, other construction and industrial materials, and industrial packaging.

The raw data gave quantities of resin used and were adjusted by the plastics process input-output coefficients to provide the estimates of plastics quantities.

Table A-5

MARKET SHARE FRACTIONS AT EQUAL PRODUCT PRICES

	End-Use Market				
Plastic	**Food**	**Medical**	**Auto**	**Consumer**	**Other**
PVC with DEHP	0.03	0.10	0.25	0.10	0.05
Regular PVC	0.03	0.10	0.25	0.20	0.15
Low Migration PVC	0.08	0.80	0.50		
Polyethylene	0.42			0.35	0.55
Other Plastics	0.44			0.35	0.25

	Input Factor Market		
Plasticizer	**Plasticizer Used in Regular PVC**	**Plasticizer Used in Low Migration PVC**	**Plasticizer Used in Other Plastics**
Large Molecular Weight Phthalate Esters	0.40		
Very Large Molecular Weight Phthalate Esters		0.25	
Small Molecular Weight Phthalate Esters	0.03		0.50
Epoxidized Soy Oil	0.17	0.75	0.50
Other Primary Plasticizers	0.40		

Table A-6

ESTIMATES OF QUANTITIES PRODUCED AND DEMANDED (1978)

(all quantities in thousands of metric tons)

Plastics Demand Quantities	
Food Packaging, Wrapping, and Containers	1,505
Medical Supplies	34
Automobile Interiors	199
Other Consumer Products	2,127
Other Flexible Plastics Uses	5,021
Plastics Quantities	
PVC made with DEHP	703
Regular PVC Plastic (non-DEHP)	1,451
Low Migration PVC Plastic	156
PE Plastic	4,755
Other Plastics	1,652
Plasticizer Quantities	
DEHP	189
Large Molecular Weight Phthalate Esters	260
Very Large Molecular Weight Phthalate Esters	18
Small Molecular Weight Phthalate Esters	135
Epoxidized Soy Oil	34
Other Primary Plasticizers	76
Resin Quantities	
PVC Resin	1,780
PE Resin	4,995
Other Resins	1,640
Feedstock Quantities	
Fossil Liquids	12,000
Cellulose	30

Plasticizer quantities, also listed in Table A-6, were derived from data in [14] and [15]. These data were adjusted to be consistent with initial plasticizer demand from the plastics sector.

Estimates of initial quantities of feedstocks used were developed by inferring the quantities required to support resin and plasticizer production. The GEMS algorithm did not require estimates of quantities of vegetable oil or chlorine since these materials do not pass through an economic market.

FLEXIBLE PLASTICS DEMAND

The demand for flexible plastics is described in the prototype model by three types of data: quantities demanded in the first year (1978), the rate of demand growth given constant real prices, and price elasticities.

Quantities demanded (used) in 1978 in each end-use market were taken from the initial quantity estimates listed in Table A-6. These data required no further adjustment.

Rates of growth in demand are summarized in Table A-7. These growth rates are those projected if prices in constant dollars remain unchanged, that is, if prices move up only by the annual inflation rate. Estimates of growth in demand for PVC were found in [14], for plasticizers in [3], and for plastics end uses in [15].

The demand model represents both short- and long-run responses of plastics consumers to changes in plastics prices. These characteristics

Table A-7

DEMAND GROWTH RATES

End Use	Average Annual Growth Rate
Food-Related	3%
Medical	5%
Automobile	5%
Consumer Products	3%
Other	2%

are modeled using short- and long-run price elasticities. The short-run elasticity for all end uses was assumed to be -0.10, while the long-run elasticity was -0.20. The long-run elasticity shows a greater sensitivity to price changes, reflecting the increased ability over the long run to change capital equipment, manufacturing techniques, and buying patterns. The elasticities used are based on DFI experience in modeling similar industrial sectors [19,23].

FEEDSTOCK PRICES

Future price estimates for feedstocks were developed from information in Synthetic Organic Chemicals [4], the Agricultural Statistics [17], and three national energy-economic system models: the Long-Range Energy Analysis Program (LEAP) used by the Energy Information Agency of the U.S. Department of Energy [18], the Integrated Forecasting Model (IFM) used by the Electric Power Research Institute [19], and the Salant Energy Reference Model [20,25]. Prices over the next twenty years are listed in Table A-8. The prices for the generic fossil liquid feedstock reflect the cost of conversion from crude oil and natural gas to an ethane/propane mix. All prices are in constant 1978 dollars (that is, they do not include inflation).

The fossil liquids price estimates used in the prototype model represent an average of projections from the three energy models. Prices for vegetable oils (primarily soy oil) are assumed to remain constant in constant dollars; the price used is based on data in [17]. The cellulose supply was included in the prototype model design as a feedstock for "other resins" but does not play a significant role in the results. Chlorine prices, data for which were also found in [16], are assumed to rise quite rapidly due to the high use of energy in producing chlorine.

SUMMARY

We have presented a description of the data used in the prototype plastics industry model. The purpose of the model and data base is to

Table A-8

FEEDSTOCK PRICES
(all prices in $/metric ton)

Year	Fossil Liquid	Chlorine	Vegetable Oils	Cellulose
1978	$ 172	$ 294	$ 620	$ 260
1980	265	312	620	275
1982	288	331	620	290
1984	313	352	620	305
1986	337	372	620	320
1988	358	395	620	340
1990	381	419	620	360
1992	402	436	620	385
1994	424	454	620	410
1996	446	472	620	435
1998	467	491	620	460
2000	489	511	620	490

illustrate the application of detailed market models to the analysis of the economic impacts of potential toxic substances regulatory decisions. We believe the data used are adequate to meet that goal and to give a reasonable indication of the economic behavior of the plastics industry. The amount of effort devoted to developing the data base was deliberately limited, as the primary emphasis of this project was on the methodology of modeling and decision analysis. The data, as well as the prototype model, would require careful refinement before being used in an actual regulatory decision analysis.

Appendix B

RESULTS OF POLICY AND SENSITIVITY ANALYSIS CASES USING THE PROTOTYPE PLASTICS INDUSTRY MODEL

This appendix contains the complete quantitative results for the policy and sensitivity analysis cases using the prototype plastics industry model. An index to the results follows.

The cases involving a complete ban on DEHP require a special explanation. The results for these cases show very high prices for DEHP, although production and use of the material has been prohibited. This is because the GEMS software implements a ban or prohibition by setting prices high enough that the demand for the material is zero. These DEHP prices have no effect on other model results and can be ignored.

Index to the Results

Case	Page
Prohibit DEHP	B-2
Restrict DEHP	B-8
Restrict DEHP and constrain production	B-14
High fossil feedstock prices	B-20
Low fossil feedstock prices	B-26
Prohibit DEHP, with high fossil feedstock prices	B-32
Prohibit DEHP, with low fossil feedstock prices	B-38

RESULTS FOR CASE WITH A COMPLETE PROHIBITION ON THE PRODUCTION AND USE OF DEHP

```
REPORT #  1

     PLASTICS PRODUCTION

                                          MATERIAL

                              +-----------+-----------+-----------+-----------+-----------+
AF=  SUM                      | PVC WITH  | REGULAR   | LOW MIG.  | PE        | OTHER     |
GSS= QUANTITY                 | DEHP      | PVC       |  PVC      | PLASTIC   | PLASTICS  |
------------------------------+-----------+-----------+-----------+-----------+-----------+
TIME                          |     1     |     2     |     3     |     4     |     5     |
-------------------------+----+-----------+-----------+-----------+-----------+-----------+
1978                     |  1 |      0.00 |   1654.29 |    188.46 |   5222.95 |   1820.30 |
1980                     |  2 |      0.00 |   1653.08 |    234.03 |   5195.46 |   2075.31 |
1982                     |  3 |      0.00 |   1683.97 |    274.37 |   5276.99 |   2262.00 |
1984                     |  4 |      0.00 |   1736.33 |    311.54 |   5433.17 |   2410.09 |
1986                     |  5 |      0.00 |   1801.78 |    346.85 |   5633.58 |   2534.76 |
1988                     |  6 |      0.00 |   1871.19 |    381.10 |   5871.59 |   2649.99 |
1990                     |  7 |      0.00 |   1944.77 |    415.61 |   6135.56 |   2758.92 |
1992                     |  8 |      0.00 |   2029.99 |    452.18 |   6418.98 |   2864.10 |
1994                     |  9 |      0.00 |   2124.21 |    491.37 |   6719.57 |   2967.82 |
1996                     | 10 |      0.00 |   2226.22 |    533.71 |   7036.35 |   3072.21 |
1998                     | 11 |      0.00 |   2333.66 |    579.51 |   7373.52 |   3180.89 |
2000                     | 12 |      0.00 |   2447.07 |    629.48 |   7729.37 |   3293.74 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

```
REPORT #  2

     PLASTICIZER PRODUCTION


                              +-----------+-----------+-----------+-----------+-----------+-----------
AF=  SUM                      | DEHP      | LG.MOL.   | SML.MOL.  | VL.MOL.   | EPOXID.   | OTHER
GSS= QUANTITY                 |           | WT.PAE    | WT.PAE    | WT.PAE    | SOY OIL   | PLASTCRS
------------------------------+-----------+-----------+-----------+-----------+-----------+-----------
TIME                          |     1     |     2     |     3     |     4     |     5     |     6
-------------------------+----+-----------+-----------+-----------+-----------+-----------+-----------
1978                     |  1 |      0.00 |    320.30 |    155.03 |     27.94 |     46.50 |     93.63
1980                     |  2 |      0.00 |    325.28 |    164.14 |     40.84 |     45.05 |     98.36
1982                     |  3 |      0.00 |    332.86 |    172.09 |     50.98 |     46.89 |    103.85
1984                     |  4 |      0.00 |    342.29 |    179.22 |     58.48 |     52.09 |    110.03
1986                     |  5 |      0.00 |    352.82 |    185.70 |     63.86 |     60.06 |    116.60
1988                     |  6 |      0.00 |    363.32 |    192.04 |     67.80 |     69.92 |    123.06
1990                     |  7 |      0.00 |    373.88 |    198.16 |     70.61 |     81.81 |    129.56
1992                     |  8 |      0.00 |    386.23 |    204.27 |     72.97 |     95.41 |    136.63
1994                     |  9 |      0.00 |    399.78 |    210.35 |     74.95 |    110.88 |    144.16
1996                     | 10 |      0.00 |    414.33 |    216.47 |     76.70 |    128.24 |    152.09
1998                     | 11 |      0.00 |    429.68 |    222.97 |     78.53 |    146.98 |    160.19
2000                     | 12 |      0.00 |    445.56 |    229.56 |     80.24 |    168.02 |    168.62

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

REPORT # 3

FOOD PACKAGING AND CONTAINERS

MATERIAL

AF= SUM GSS= QUANTITY TIME		PVC WITH DEHP 1	REGULAR PVC 2	LOW MIG. PVC 3	PE PLASTIC 4	OTHER PLASTICS 5
1978	1	0.00	63.61	67.71	872.02	501.67
1980	2	0.00	62.27	89.71	859.10	554.67
1982	3	0.00	62.83	107.63	871.20	597.51
1984	4	0.00	64.65	122.72	900.81	635.16
1986	5	0.00	67.27	135.76	941.56	669.84
1988	6	0.00	70.20	146.94	991.26	703.96
1990	7	0.00	73.41	157.12	1047.63	737.82
1992	8	0.00	77.19	167.49	1109.61	771.94
1994	9	0.00	81.41	178.26	1176.58	806.61
1996	10	0.00	86.01	189.60	1248.23	842.21
1998	11	0.00	90.88	201.40	1325.18	879.55
2000	12	0.00	96.03	213.95	1407.17	918.56

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 4

MEDICAL SUPPLIES

MATERIALS

AF= SUM GSS= QUANTITY TIME		PVC WITH DEHP 1	REGULAR PVC 2	LOW MIG. PVC 3
1978	1	0.00	12.75	21.25
1980	2	0.00	10.35	26.58
1982	3	0.00	8.95	31.35
1984	4	0.00	8.21	35.86
1986	5	0.00	7.93	40.31
1988	6	0.00	7.99	44.84
1990	7	0.00	8.28	49.58
1992	8	0.00	8.77	54.66
1994	9	0.00	9.40	60.14
1996	10	0.00	10.16	66.09
1998	11	0.00	11.03	72.61
2000	12	0.00	12.01	79.75

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 5

AUTOMOBILE USES

MATERIAL

AF= SUM GSS= QUANTITY		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC
TIME		1	2	3
1978	1	0.00	99.50	99.50
1980	2	0.00	98.34	117.74
1982	3	0.00	100.32	135.39
1984	4	0.00	104.83	152.96
1986	5	0.00	111.40	170.78
1988	6	0.00	119.74	189.32
1990	7	0.00	129.61	208.91
1992	8	0.00	141.01	230.04
1994	9	0.00	153.82	252.97
1996	10	0.00	168.03	278.01
1998	11	0.00	183.73	305.50
2000	12	0.00	200.92	335.79

QUANTITIES THOUSANDS OF METRIC TONS.

REPORT # 6

OTHER CONSUMER PRODUCTS

MATERIAL

AF= SUM GSS= QUANTITY		PVC WITH DEHP	REGULAR PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4
1978	1	0.00	598.37	957.63	571.01
1980	2	0.00	594.23	982.40	638.30
1982	3	0.00	605.38	1022.57	691.85
1984	4	0.00	626.72	1074.59	737.97
1986	5	0.00	654.42	1134.24	779.69
1988	6	0.00	684.67	1201.69	820.61
1990	7	0.00	717.24	1275.23	861.07
1992	8	0.00	754.77	1353.60	901.25
1994	9	0.00	796.25	1436.79	941.71
1996	10	0.00	841.24	1524.90	983.06
1998	11	0.00	888.79	1619.27	1026.49
2000	12	0.00	939.15	1719.72	1071.94

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 7

PLASTICS PRICES

		MATERIAL				
AF= AVERAGE PRICE GSS= PRICES		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	0.00	827.28	886.73	801.16	838.06
1980	2	*********	932.05	979.55	932.71	996.52
1982	3	*********	965.16	1008.63	965.42	1036.18
1984	4	*********	1001.54	1043.81	1000.95	1079.18
1986	5	*********	1036.55	1079.02	1035.04	1120.32
1988	6	949686.19	1069.90	1113.10	1064.92	1156.64
1990	7	890317.88	1105.80	1149.86	1097.60	1196.28
1992	8	827662.88	1136.33	1181.16	1127.47	1232.97
1994	9	766962.25	1168.42	1213.75	1158.80	1271.42
1996	10	707350.00	1201.09	1246.61	1190.73	1310.54
1998	11	653002.44	1232.06	1277.64	1219.97	1346.71
2000	12	593652.00	1263.60	1308.54	1250.07	1383.47

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 8

PLASTICIZER PRICES

AF= AVERAGE PRICE GSS= PRICES		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	0.00	815.72	884.25	884.74	1280.59	940.79
1980	2	59223.98	1022.57	1066.88	1111.89	1435.12	1162.45
1982	3	59627.52	1074.09	1112.27	1168.33	1473.46	1217.49
1984	4	60019.69	1129.94	1161.57	1229.63	1515.11	1277.29
1986	5	60015.22	1183.53	1208.88	1288.45	1555.07	1334.67
1988	6	59430.19	1230.48	1250.32	1339.98	1590.07	1384.95
1990	7	58856.46	1281.85	1295.66	1396.35	1628.37	1439.97
1992	8	57874.85	1328.78	1337.08	1447.85	1663.35	1490.24
1994	9	56815.89	1377.92	1380.45	1501.79	1699.99	1542.90
1996	10	55584.59	1427.18	1423.92	1555.81	1736.49	1595.70
1998	11	54295.27	1466.19	1457.23	1598.71	1764.43	1637.76
2000	12	52814.66	1517.90	1503.14	1655.41	1803.16	1693.26

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 13

AVERAGE PLASTICS PRICES

AF= AVERAGE PRICE GSS= PRICES		PLASTICS FOOD USES	 MEDICAL SUPPLIES	 AUTO USES	 CONSUMER PRODUCTS	 OTHER DEMAND
TIME		1	2	3	4	5
1978	1	818.42	864.43	857.00	818.41	811.23
1980	2	957.98	966.23	957.93	950.93	943.59
1982	3	994.05	998.98	990.13	986.46	978.46
1984	4	1032.87	1035.94	1026.63	1024.78	1016.01
1986	5	1069.89	1072.04	1062.26	1061.33	1051.83
1988	6	1102.59	1106.57	1096.37	1094.00	1083.60
1990	7	1138.11	1143.56	1133.00	1129.46	1118.12
1992	8	1170.35	1174.97	1164.13	1161.31	1149.27
1994	9	1204.05	1207.63	1196.62	1194.65	1181.88
1996	10	1238.27	1240.55	1229.47	1228.54	1215.04
1998	11	1269.75	1271.63	1260.53	1259.86	1245.59
2000	12	1301.86	1302.66	1291.72	1291.86	1276.86

PRICES IN DOLLARS PER METRIC TON.

RESULTS FOR THE CASE WITH RESTRICTIONS ON THE USE OF DEHP

REPORT # 1

PLASTICS PRODUCTION

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC	 PE PLASTIC	 OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	640.76	1519.22	185.80	4860.78	1679.44
1980	2	693.46	1576.60	203.95	4956.74	1732.27
1982	3	740.12	1645.21	226.01	5118.53	1776.41
1984	4	783.96	1721.73	249.73	5329.81	1817.59
1986	5	826.15	1802.93	274.10	5569.34	1858.40
1988	6	862.70	1878.47	298.19	5844.02	1906.15
1990	7	896.63	1952.78	322.89	6142.21	1957.47
1992	8	935.64	2039.65	349.92	6450.11	2008.69
1994	9	978.32	2136.00	379.56	6768.93	2060.64
1996	10	1024.10	2240.51	412.17	7099.45	2114.52
1998	11	1070.98	2349.50	447.73	7449.76	2173.57
2000	12	1119.32	2463.86	486.92	7818.59	2236.56

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 2

PLASTICIZER PRODUCTION

AF= SUM GSS= QUANTITY		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	179.41	294.15	142.87	27.54	44.42	85.98
1980	2	194.17	310.29	140.49	35.59	39.70	93.74
1982	3	207.23	325.30	140.01	42.01	39.62	101.34
1984	4	219.51	339.55	140.82	46.90	43.03	108.95
1986	5	231.32	353.20	142.48	50.49	48.99	116.49
1988	6	241.55	364.91	145.02	53.08	56.55	123.34
1990	7	251.06	375.59	148.05	54.89	65.79	129.89
1992	8	261.98	388.25	151.38	56.50	76.50	137.06
1994	9	273.93	402.19	154.94	57.93	88.80	144.74
1996	10	286.75	417.19	158.72	59.28	102.73	152.84
1998	11	299.87	432.72	162.91	60.68	117.98	161.09
2000	12	313.41	448.71	167.32	62.07	135.06	169.62

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 3

FOOD PACKAGING AND CONTAINERS

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC	 PE PLASTIC	 OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	59.14	61.11	65.05	837.75	481.95
1980	2	66.75	62.63	81.33	863.48	492.35
1982	3	73.21	65.10	96.42	902.06	503.82
1984	4	79.11	68.21	110.00	951.21	516.81
1986	5	84.71	71.73	122.07	1007.18	531.23
1988	6	89.56	75.02	132.06	1070.39	548.23
1990	7	94.07	78.29	140.94	1139.17	566.78
1992	8	99.19	82.20	150.31	1212.04	586.17
1994	9	104.79	86.60	160.29	1288.94	606.36
1996	10	110.79	91.39	171.03	1369.88	627.53
1998	11	116.94	96.36	182.24	1456.04	650.42
2000	12	123.30	101.56	194.27	1547.33	674.67

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 4

MEDICAL SUPPLIES

AF= SUM GSS= QUANTITY		MATERIALS PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC
TIME		1	2	3
1978	1	0.00	12.75	21.25
1980	2	0.00	12.55	24.40
1982	3	0.00	12.65	27.67
1984	4	0.00	13.06	31.05
1986	5	0.00	13.73	34.55
1988	6	0.00	14.64	38.25
1990	7	0.00	15.74	42.19
1992	8	0.00	17.03	46.46
1994	9	0.00	18.49	51.12
1996	10	0.00	20.10	56.22
1998	11	0.00	21.87	61.84
2000	12	0.00	23.79	68.05

QUANTITIES IN THOUSANDS OF METRIC TONS.

```
REPORT #  5

AUTOMOBILE USES

                                         MATERIAL
                              +----------+----------+----------+
AF=  SUM                      | PVC WITH | REGULAR  | LOW MIG. |
GSS= QUANTITY                 | DEHP     | PVC      | PVC      |
------------------------------+----------+----------+----------+
TIME                          |    1     |    2     |    3     |
-------------------------+----+----------+----------+----------+
1978                     |  1 |     0.00 |    99.50 |    99.50 |
1980                     |  2 |     0.00 |   117.99 |    98.22 |
1982                     |  3 |     0.00 |   134.04 |   101.91 |
1984                     |  4 |     0.00 |   149.45 |   108.68 |
1986                     |  5 |     0.00 |   165.12 |   117.48 |
1988                     |  6 |     0.00 |   181.66 |   127.88 |
1990                     |  7 |     0.00 |   199.30 |   139.76 |
1992                     |  8 |     0.00 |   218.49 |   153.15 |
1994                     |  9 |     0.00 |   239.29 |   168.16 |
1996                     | 10 |     0.00 |   261.83 |   184.92 |
1998                     | 11 |     0.00 |   286.34 |   203.65 |
2000                     | 12 |     0.00 |   312.90 |   224.61 |

QUANTITIES THOUSANDS OF METRIC TONS.
```

```
REPORT #  6

   OTHER CONSUMER PRODUCTS

                                         MATERIAL
                              +----------+----------+----------+----------+
AF=  SUM                      | PVC WITH | REGULAR  | PE       | OTHER    |
GSS= QUANTITY                 | DEHP     | PVC      | PLASTIC  | PLASTICS |
------------------------------+----------+----------+----------+----------+
TIME                          |    1     |    2     |    3     |    4     |
-------------------------+----+----------+----------+----------+----------+
1978                     |  1 |   288.88 |   517.10 |   827.57 |   493.46 |
1980                     |  2 |   307.04 |   530.54 |   877.48 |   501.95 |
1982                     |  3 |   325.80 |   552.03 |   932.90 |   512.50 |
1984                     |  4 |   345.45 |   578.87 |   994.26 |   525.03 |
1986                     |  5 |   365.80 |   608.94 |  1059.46 |   539.22 |
1988                     |  6 |   384.92 |   638.23 |  1132.31 |   557.14 |
1990                     |  7 |   403.72 |   667.78 |  1210.91 |   577.23 |
1992                     |  8 |   425.18 |   702.02 |  1291.55 |   597.53 |
1994                     |  9 |   448.68 |   739.90 |  1375.16 |   618.31 |
1996                     | 10 |   473.99 |   780.95 |  1462.29 |   639.91 |
1998                     | 11 |   500.30 |   823.85 |  1555.45 |   663.53 |
2000                     | 12 |   527.75 |   868.93 |  1654.55 |   688.79 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

```
REPORT #  7

     PLASTICS PRICES

                                              MATERIAL
                           +--------------+-------------+-------------+-------------+-------------+
AF=  AVERAGE PRICE         | PVC WITH     | REGULAR     | LOW MIG.    | PE          | OTHER       |
GSS= PRICES                | DEHP         | PVC         |  PVC        | PLASTIC     | PLASTICS    |
---------------------------+--------------+-------------+-------------+-------------+-------------+
TIME                       |      1       |      2      |      3      |      4      |      5      |
----------------------+----+--------------+-------------+-------------+-------------+-------------+
1978                  |  1 |     808.54   |     827.28  |     886.73  |     801.16  |     838.06  |
1980                  |  2 |     912.49   |     932.05  |     979.55  |     932.71  |     996.52  |
1982                  |  3 |     945.21   |     965.16  |    1008.63  |     965.42  |    1036.18  |
1984                  |  4 |     980.91   |    1001.55  |    1043.81  |    1000.95  |    1079.18  |
1986                  |  5 |    1015.10   |    1036.55  |    1079.02  |    1035.04  |    1120.32  |
1988                  |  6 |    1047.65   |    1069.90  |    1113.10  |    1064.92  |    1156.64  |
1990                  |  7 |    1082.68   |    1105.80  |    1149.86  |    1097.60  |    1196.28  |
1992                  |  8 |    1112.39   |    1136.33  |    1181.16  |    1127.47  |    1232.97  |
1994                  |  9 |    1143.64   |    1168.42  |    1213.75  |    1158.80  |    1271.42  |
1996                  | 10 |    1175.47   |    1201.09  |    1246.61  |    1190.73  |    1310.54  |
1998                  | 11 |    1205.68   |    1232.06  |    1277.64  |    1219.97  |    1346.71  |
2000                  | 12 |    1236.58   |    1263.60  |    1308.54  |    1250.07  |    1383.47  |

AVERAGE PRICES IN DOLLARS PER METRIC TON.
```

```
REPORT #  8

     PLASTICIZER PRICES

                           +-------------+-------------+-------------+-------------+-------------+-------------+
AF=  AVERAGE PRICE         | DEHP        | LG.MOL.     | SML.MOL.    | VL.MOL.     | EPOXID.     | OTHER       |
GSS= PRICES                |             | WT.PAE      | WT.PAE      | WT.PAE      | SOY OIL     | PLASTCRS    |
---------------------------+-------------+-------------+-------------+-------------+-------------+-------------+
TIME                       |      1      |      2      |      3      |      4      |      5      |      6      |
----------------------+----+-------------+-------------+-------------+-------------+-------------+-------------+
1978                  |  1 |     791.98  |     815.72  |     884.25  |     884.74  |    1280.59  |     940.79  |
1980                  |  2 |     994.42  |    1022.67  |    1066.88  |    1111.89  |    1435.12  |    1162.45  |
1982                  |  3 |    1044.71  |    1074.09  |    1112.27  |    1168.33  |    1473.46  |    1217.49  |
1984                  |  4 |    1099.35  |    1129.94  |    1161.57  |    1229.63  |    1515.11  |    1277.29  |
1986                  |  5 |    1151.77  |    1183.53  |    1208.88  |    1288.45  |    1555.07  |    1334.67  |
1988                  |  6 |    1197.70  |    1230.48  |    1250.32  |    1339.98  |    1590.07  |    1384.95  |
1990                  |  7 |    1247.94  |    1281.85  |    1295.66  |    1396.35  |    1628.37  |    1439.97  |
1992                  |  8 |    1293.85  |    1328.78  |    1337.08  |    1447.85  |    1663.35  |    1490.24  |
1994                  |  9 |    1341.94  |    1377.92  |    1380.45  |    1501.79  |    1699.99  |    1542.90  |
1996                  | 10 |    1390.13  |    1427.18  |    1423.92  |    1555.81  |    1736.49  |    1595.70  |
1998                  | 11 |    1428.42  |    1466.19  |    1457.23  |    1598.71  |    1764.43  |    1637.76  |
2000                  | 12 |    1479.02  |    1517.90  |    1503.14  |    1655.41  |    1803.16  |    1693.26  |

AVERAGE PRICES IN DOLLARS PER METRIC TON.
```

REPORT # 13

AVERAGE PLASTICS PRICES

		PLASTICS				
AF= AVERAGE PRICE GSS= PRICES		FOOD USES	MEDICAL SUPPLIES	AUTO USES	CONSUMER PRODUCTS	OTHER DEMAND
TIME		1	2	3	4	5
1978	1	818.03	864.43	857.00	817.07	811.08
1980	2	954.31	963.42	953.63	944.19	940.52
1982	3	988.77	994.99	983.94	978.13	974.28
1984	4	1026.21	1031.30	1019.34	1015.06	1010.89
1986	5	1062.05	1066.95	1054.21	1050.42	1045.93
1988	6	1093.87	1101.15	1087.75	1082.47	1077.25
1990	7	1128.56	1137.89	1123.96	1117.22	1111.34
1992	8	1159.93	1169.14	1154.81	1148.30	1141.95
1994	9	1192.77	1201.71	1187.13	1180.78	1174.04
1996	10	1226.16	1234.63	1219.94	1213.82	1206.70
1998	11	1256.91	1265.73	1251.01	1244.50	1236.85
2000	12	1288.36	1296.90	1282.39	1275.90	1267.77

PRICES IN DOLLARS PER METRIC TON.

RESULTS FOR THE CASE WITH RESTRICTIONS ON THE USE OF DEHP AND A CONSTRAINT ON THE TOTAL QUANTITY OF DEHP THAT MAY BE PRODUCED

```
REPORT #  1

        PLASTICS PRODUCTION

                                         MATERIAL
                           +----------+----------+----------+----------+----------+
AF=  SUM                   | PVC WITH | REGULAR  | LOW MIG. | PE       | OTHER    |
GSS= QUANTITY              | DEHP     | PVC      |  PVC     | PLASTIC  | PLASTICS |
---------------------------+----------+----------+----------+----------+----------+
TIME                       |    1     |    2     |    3     |    4     |    5     |
----------------------+----+----------+----------+----------+----------+----------+
1978                  |  1 |   640.76 |  1519.22 |   185.80 |  4860.78 |  1679.44 |
1980                  |  2 |   795.95 |  1563.36 |   206.37 |  4930.16 |  1667.18 |
1982                  |  3 |   803.06 |  1656.84 |   230.48 |  5121.62 |  1693.51 |
1984                  |  4 |   803.88 |  1760.07 |   252.89 |  5362.18 |  1722.43 |
1986                  |  5 |   804.81 |  1860.67 |   277.03 |  5626.20 |  1760.40 |
1988                  |  6 |   805.36 |  1944.81 |   299.39 |  5925.46 |  1812.18 |
1990                  |  7 |   805.97 |  2011.99 |   322.44 |  6260.76 |  1867.81 |
1992                  |  8 |   806.72 |  2130.71 |   348.01 |  6583.74 |  1911.12 |
1994                  |  9 |   807.86 |  2240.87 |   376.90 |  6925.95 |  1967.10 |
1996                  | 10 |   808.76 |  2359.77 |   409.34 |  7279.70 |  2027.17 |
1998                  | 11 |   809.17 |  2488.60 |   443.64 |  7652.16 |  2090.99 |
2000                  | 12 |   810.44 |  2603.67 |   480.14 |  8058.88 |  2159.14 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

```
REPORT #  2

        PLASTICIZER PRODUCTION

                         +----------+----------+----------+----------+----------+----------+
AF=  SUM                 | DEHP     | LG.MOL.  | SML.MOL. | VL.MOL.  | EPOXID.  | OTHER    |
GSS= QUANTITY            |          | WT.PAE   | WT.PAE   | WT.PAE   | SOY OIL  | PLASTCRS |
-------------------------+----------+----------+----------+----------+----------+----------+
TIME                     |    1     |    2     |    3     |    4     |    5     |    6     |
--------------------+----+----------+----------+----------+----------+----------+----------+
1978                |  1 |   179.41 |   276.50 |   136.98 |    26.01 |    55.51 |    99.96 |
1980                |  2 |   222.87 |   316.65 |   136.50 |    35.83 |    45.30 |    77.95 |
1982                |  3 |   224.86 |   354.41 |   139.70 |    43.74 |    42.04 |    67.10 |
1984                |  4 |   225.09 |   386.59 |   143.45 |    49.29 |    43.10 |    61.77 |
1986                |  5 |   225.35 |   413.11 |   147.87 |    53.60 |    47.59 |    59.61 |
1988                |  6 |   225.50 |   432.74 |   152.93 |    56.49 |    54.03 |    59.03 |
1990                |  7 |   225.67 |   446.19 |   157.91 |    58.55 |    62.40 |    59.33 |
1992                |  8 |   225.88 |   469.53 |   163.07 |    60.41 |    72.84 |    61.97 |
1994                |  9 |   226.20 |   489.67 |   168.84 |    62.18 |    85.10 |    64.87 |
1996                | 10 |   226.45 |   510.66 |   174.97 |    63.94 |    99.35 |    68.33 |
1998                | 11 |   226.57 |   533.20 |   181.65 |    65.69 |   114.68 |    72.19 |
2000                | 12 |   226.92 |   552.85 |   188.21 |    67.13 |   131.89 |    75.92 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

REPORT # 3

FOOD PACKAGING AND CONTAINERS

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	59.14	61.11	65.05	837.75	481.95
1980	2	68.26	61.82	89.92	860.58	485.84
1982	3	68.61	65.27	107.07	903.96	495.47
1984	4	69.44	69.64	118.31	959.97	507.69
1986	5	69.95	74.11	129.41	1020.16	522.92
1988	6	69.82	77.73	137.33	1088.81	541.16
1990	7	66.35	81.39	144.68	1163.09	563.27
1992	8	72.73	85.81	152.99	1236.59	581.22
1994	9	71.58	90.49	162.73	1316.36	605.11
1996	10	72.13	96.39	173.96	1401.52	625.76
1998	11	72.18	101.84	184.72	1489.21	653.07
2000	12	73.47	106.82	194.78	1586.12	678.83

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 4

MEDICAL SUPPLIES

AF= SUM GSS= QUANTITY		MATERIALS PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC
TIME		1	2	3
1978	1	0.00	12.75	21.25
1980	2	0.00	11.91	25.01
1982	3	0.00	11.94	28.36
1984	4	0.00	12.50	31.60
1986	5	0.00	13.39	34.88
1988	6	0.00	14.52	38.36
1990	7	0.00	15.83	42.10
1992	8	0.00	17.31	46.18
1994	9	0.00	18.93	50.68
1996	10	0.00	20.68	55.64
1998	11	0.00	22.59	61.12
2000	12	0.00	24.62	67.21

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 5

AUTOMOBILE USES

AF= SUM GSS= QUANTITY		MATERIAL		
		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC
TIME		1	2	3
1978	1	0.00	99.50	99.50
1980	2	0.00	124.70	91.44
1982	3	0.00	140.91	95.06
1984	4	0.00	155.22	102.99
1986	5	0.00	169.99	112.73
1988	6	0.00	186.00	123.69
1990	7	0.00	203.56	135.67
1992	8	0.00	222.98	148.84
1994	9	0.00	244.15	163.49
1996	10	0.00	267.21	179.73
1998	11	0.00	292.39	197.80
2000	12	0.00	319.56	218.14

QUANTITIES THOUSANDS OF METRIC TONS.

REPORT # 6

OTHER CONSUMER PRODUCTS

AF= SUM GSS= QUANTITY		MATERIAL			
		PVC WITH DEHP	REGULAR PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4
1978	1	288.88	517.10	827.57	493.46
1980	2	403.20	511.41	874.83	428.15
1982	3	419.18	542.17	932.55	429.68
1984	4	426.43	582.83	996.29	438.09
1986	5	424.66	623.28	1071.20	454.02
1988	6	432.42	659.08	1150.13	470.36
1990	7	445.16	677.85	1239.90	495.69
1992	8	444.52	739.22	1318.05	513.04
1994	9	445.72	782.35	1420.38	531.53
1996	10	455.02	831.79	1513.30	554.29
1998	11	460.54	887.74	1611.95	579.61
2000	12	456.49	940.98	1737.04	601.66

QUANTITIES IN THOUSANDS OF METRIC TONS.

```
REPORT #  7

       PLASTICS PRICES

                                            MATERIAL
                           +---------+---------+---------+---------+---------+
AF=  AVERAGE PRICE         | PVC WITH | REGULAR  | LOW MTG. | PE       | OTHER    |
GSS= PRICES                | DEHP     | PVC      |  PVC     | PLASTIC  | PLASTICS |
---------------------------+---------+---------+---------+---------+---------+
TIME                       |    1    |    2    |    3    |    4    |    5    |
-----------------------+---+---------+---------+---------+---------+---------+
1978                   | 1 |  808.54 |  831.83 |  895.22 |  801.16 |  839.25 |
1980                   | 2 |  912.49 |  933.09 |  983.79 |  932.71 |  997.13 |
1982                   | 3 |  962.78 |  964.00 | 1010.77 |  965.42 | 1036.47 |
1984                   | 4 | 1005.17 |  998.98 | 1044.92 | 1000.95 | 1079.28 |
1986                   | 5 | 1045.28 | 1033.08 | 1079.73 | 1035.04 | 1120.31 |
1988                   | 6 | 1083.87 | 1065.85 | 1113.79 | 1064.92 | 1156.57 |
1990                   | 7 | 1125.91 | 1101.35 | 1150.80 | 1097.60 | 1196.17 |
1992                   | 8 | 1161.87 | 1131.62 | 1182.48 | 1127.47 | 1232.84 |
1994                   | 9 | 1204.04 | 1163.51 | 1215.55 | 1158.80 | 1271.29 |
1996                   |10 | 1246.61 | 1196.03 | 1248.96 | 1190.73 | 1310.41 |
1998                   |11 | 1283.88 | 1226.88 | 1280.52 | 1219.97 | 1346.59 |
2000                   |12 | 1322.81 | 1258.34 | 1311.94 | 1250.07 | 1383.37 |

AVERAGE PRICES IN DOLLARS PER METRIC TON.
```

```
REPORT #  8

       PLASTICIZER PRICES

                           +---------+---------+---------+---------+---------+---------+
AF=  AVERAGE PRICE         | DEHP     | LG.MOL.  | SML.MOL. | VL.MOL.  | EPOXID.  | OTHER    |
GSS= PRICES                |          | WT.PAE   | WT.PAE   | WT.PAE   | SOY OIL  | PLASTCRS |
---------------------------+---------+---------+---------+---------+---------+---------+
TIME                       |    1    |    2    |    3    |    4    |    5    |    6    |
-----------------------+---+---------+---------+---------+---------+---------+---------+
1978                   | 1 |  791.98 |  815.72 |  884.25 |  884.74 | 1317.94 |  961.06 |
1980                   | 2 |  994.42 | 1022.67 | 1066.88 | 1111.89 | 1472.47 | 1182.74 |
1982                   | 3 | 1044.71 | 1074.09 | 1112.27 | 1168.33 | 1510.80 | 1237.78 |
1984                   | 4 | 1099.35 | 1129.94 | 1161.57 | 1229.63 | 1552.45 | 1297.58 |
1986                   | 5 | 1151.77 | 1183.53 | 1208.88 | 1288.45 | 1592.41 | 1354.97 |
1988                   | 6 | 1197.70 | 1230.48 | 1250.32 | 1339.98 | 1627.40 | 1405.26 |
1990                   | 7 | 1247.94 | 1281.85 | 1295.66 | 1396.35 | 1665.70 | 1460.28 |
1992                   | 8 | 1293.85 | 1328.78 | 1337.08 | 1447.85 | 1700.68 | 1510.55 |
1994                   | 9 | 1341.94 | 1377.92 | 1380.45 | 1501.79 | 1737.31 | 1563.21 |
1996                   |10 | 1390.13 | 1427.18 | 1423.92 | 1555.81 | 1773.80 | 1616.02 |
1998                   |11 | 1428.42 | 1466.19 | 1457.23 | 1598.71 | 1801.71 | 1657.82 |
2000                   |12 | 1479.02 | 1517.90 | 1503.14 | 1655.41 | 1840.45 | 1713.37 |

AVERAGE PRICES IN DOLLARS PER METRIC TON.
```

```
REPORT # 13

        AVERAGE PLASTICS PRICES

                                                PLASTICS
                                    +----------+----------+----------+----------+----------+
AF=  AVERAGE PRICE                  | FOOD     | MEDICAL  | AUTO     | CONSUMER | OTHER    |
GSS= PRICES                         | USES     | SUPPLIES | USES     | PRODUCTS | DEMAND   |
------------------------------------+----------+----------+----------+----------+----------+
TIME                                |     1    |     2    |     3    |     4    |     5    |
-------------------------------+----+----------+----------+----------+----------+----------+
1978                           |  1 |   818.96 |   871.45 |   863.53 |   818.46 |   812.00 |
1980                           |  2 |   954.67 |   967.42 |   954.56 |   941.97 |   940.85 |
1982                           |  3 |   989.65 |   996.90 |   982.84 |   977.87 |   975.38 |
1984                           |  4 |  1027.16 |  1031.89 |  1017.30 |  1015.30 |  1012.07 |
1986                           |  5 |  1063.12 |  1066.79 |  1051.68 |  1051.24 |  1047.21 |
1988                           |  6 |  1095.10 |  1100.62 |  1084.99 |  1084.05 |  1078.67 |
1990                           |  7 |  1129.99 |  1137.28 |  1121.12 |  1119.75 |  1112.95 |
1992                           |  8 |  1161.57 |  1168.61 |  1151.97 |  1151.40 |  1143.75 |
1994                           |  9 |  1194.78 |  1201.39 |  1184.37 |  1185.13 |  1176.22 |
1996                           | 10 |  1228.52 |  1234.61 |  1217.30 |  1219.30 |  1209.23 |
1998                           | 11 |  1259.48 |  1266.03 |  1248.51 |  1250.59 |  1239.56 |
2000                           | 12 |  1291.20 |  1297.56 |  1280.07 |  1282.81 |  1270.72 |

PRICES IN DOLLARS PER METRIC TON.
```

RESULTS FOR THE CASE WITH HIGH FOSSIL FEEDSTOCK PRICES

REPORT # 1

PLASTICS PRODUCTION

		MATERIAL				
AF= SUM GSS= QUANTITY		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	713.92	1483.57	148.29	4860.78	1679.44
1980	2	774.21	1523.08	177.09	4955.61	1732.47
1982	3	828.85	1579.68	206.13	5108.73	1764.52
1984	4	881.79	1647.54	234.36	5303.54	1788.36
1986	5	933.84	1721.24	261.69	5513.26	1813.10
1988	6	986.06	1799.41	289.08	5720.37	1849.64
1990	7	1037.55	1879.15	317.49	5902.96	1919.41
1992	8	1085.93	1955.67	347.60	6050.41	2042.55
1994	9	1128.92	2025.58	379.96	6131.74	2254.80
1996	10	1159.55	2076.93	413.65	6115.84	2608.17
1998	11	1169.93	2096.01	447.06	5970.43	3161.36
2000	12	1158.64	2080.39	480.22	5693.27	3932.67

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 2

PLASTICIZER PRODUCTION

AF= SUM GSS= QUANTITY		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	199.90	287.24	142.08	21.98	39.21	83.96
1980	2	216.78	299.76	139.55	30.91	36.54	90.56
1982	3	232.08	311.66	138.19	37.91	38.21	97.58
1984	4	246.90	322.97	137.69	42.71	43.82	104.92
1986	5	261.48	333.25	137.98	45.40	53.15	112.36
1988	6	276.10	342.49	139.32	46.31	66.30	119.83
1990	7	290.51	350.16	142.63	45.78	83.76	127.09
1992	8	304.06	355.51	148.68	44.25	105.74	133.71
1994	9	316.10	357.89	158.98	42.00	133.19	139.33
1996	10	324.67	355.30	175.44	39.19	166.95	143.05
1998	11	327.58	345.78	199.91	36.00	207.68	143.98
2000	12	324.42	329.70	231.50	32.67	256.65	141.74

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 3

FOOD PACKAGING AND CONTAINERS

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC	 PE PLASTIC	 OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	59.14	61.11	65.05	837.75	481.95
1980	2	66.75	62.62	81.32	863.26	492.40
1982	3	73.37	65.23	96.87	901.01	500.81
1984	4	79.56	68.59	111.10	948.27	509.36
1986	5	85.47	72.37	124.05	999.71	519.57
1988	6	91.23	76.41	136.33	1051.31	533.83
1990	7	96.67	80.45	148.41	1097.21	557.49
1992	8	101.42	84.11	160.35	1133.57	595.65
1994	9	105.09	87.04	172.13	1152.20	657.40
1996	10	106.68	88.43	182.31	1144.52	754.92
1998	11	105.27	87.52	188.89	1103.43	899.95
2000	12	100.94	84.40	191.34	1031.65	1092.37

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 4

MEDICAL SUPPLIES

AF= SUM GSS= QUANTITY		MATERIALS PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC
TIME		1	2	3
1978	1	7.46	9.95	16.59
1980	2	7.38	8.57	21.05
1982	3	7.44	7.76	25.11
1984	4	7.65	7.38	28.93
1986	5	8.01	7.30	32.63
1988	6	8.47	7.44	36.36
1990	7	8.99	7.71	40.25
1992	8	9.55	8.07	44.42
1994	9	10.11	8.46	48.99
1996	10	10.63	8.87	54.03
1998	11	11.11	9.28	59.60
2000	12	11.55	9.69	65.81

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 5

AUTOMOBILE USES

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC
TIME		1	2	3
1978	1	65.70	66.65	66.65
1980	2	73.38	68.52	74.72
1982	3	80.38	71.47	84.16
1984	4	87.55	75.58	94.33
1986	5	95.15	80.65	105.01
1988	6	103.25	86.53	116.39
1990	7	111.75	93.00	128.84
1992	8	120.56	99.94	142.82
1994	9	129.51	107.20	158.84
1996	10	138.41	114.66	177.31
1998	11	147.13	122.31	198.56
2000	12	155.72	130.25	223.07

QUANTITIES THOUSANDS OF METRIC TONS.

REPORT # 6

OTHER CONSUMER PRODUCTS

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 PE PLASTIC	 OTHER PLASTICS
TIME		1	2	3	4
1978	1	288.88	517.10	827.57	493.46
1980	2	307.02	530.50	877.25	502.00
1982	3	326.13	552.66	930.88	508.96
1984	4	346.41	580.62	988.63	516.21
1986	5	367.29	611.80	1047.11	525.25
1988	6	388.98	645.16	1103.64	538.54
1990	7	410.43	679.09	1153.98	561.97
1992	8	430.51	711.50	1196.21	601.55
1994	9	447.89	740.31	1223.29	667.75
1996	10	459.21	760.27	1228.36	776.38
1998	11	460.66	765.43	1204.25	945.28
2000	12	451.50	754.81	1150.47	1180.03

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 7

PLASTICS PRICES

		MATERIAL				
AF= AVERAGE PRICE GSS= PRICES		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	808.99	827.77	887.23	801.82	838.44
1980	2	913.10	932.70	980.21	933.55	997.04
1982	3	959.07	979.31	1023.12	980.57	1053.76
1984	4	1010.57	1031.88	1075.03	1033.29	1116.69
1986	5	1067.14	1089.81	1133.57	1091.69	1184.48
1988	6	1129.82	1154.06	1198.46	1157.22	1257.43
1990	7	1201.11	1227.10	1271.21	1232.66	1334.68
1992	8	1278.97	1306.75	1349.06	1315.23	1411.70
1994	9	1366.10	1395.65	1434.16	1409.24	1487.42
1996	10	1464.36	1495.52	1528.01	1515.74	1558.20
1998	11	1575.67	1608.03	1632.68	1636.04	1622.68
2000	12	1689.82	1722.77	1737.49	1762.28	1682.31

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 8

PLASTICIZER PRICES

AF= AVERAGE PRICE GSS= PRICES		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	791.99	815.78	884.75	884.85	1280.82	940.77
1980	2	994.53	1022.83	1067.50	1112.11	1435.41	1162.51
1982	3	1066.68	1096.60	1132.63	1193.09	1490.43	1241.47
1984	4	1147.59	1179.31	1205.64	1283.87	1552.09	1330.03
1986	5	1237.26	1270.97	1286.54	1384.45	1620.41	1428.20
1988	6	1337.87	1373.81	1377.29	1497.30	1697.04	1538.39
1990	7	1453.75	1492.24	1481.78	1627.26	1785.31	1665.33
1992	8	1580.55	1621.84	1596.13	1769.46	1881.89	1804.27
1994	9	1724.80	1769.26	1726.19	1931.21	1991.75	1962.36
1996	10	1886.52	1934.50	1871.93	2112.45	2114.66	2139.75
1998	11	2058.12	2109.90	2024.87	2305.44	2245.33	2326.03
2000	12	2266.92	2323.33	2214.04	2539.36	2404.40	2556.09

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 13

AVERAGE PLASTICS PRICES

AF= AVERAGE PRICE GSS= PRICES		PLASTICS FOOD USES	 MEDICAL SUPPLIES	 AUTO USES	 CONSUMER PRODUCTS	 OTHER DEMAND
TIME		1	2	3	4	5
1978	1	818.58	852.65	841.48	817.60	811.66
1980	2	955.03	955.82	942.45	944.90	941.28
1982	3	1004.48	1002.87	988.04	993.32	989.48
1984	4	1059.65	1056.57	1040.45	1047.44	1043.32
1986	5	1120.15	1115.82	1098.50	1106.84	1102.55
1988	6	1187.12	1181.03	1162.77	1172.68	1168.43
1990	7	1262.57	1254.17	1235.44	1247.18	1243.41
1992	8	1343.49	1332.78	1314.18	1327.66	1324.75
1994	9	1432.29	1419.17	1401.46	1416.70	1415.59
1996	10	1527.65	1514.90	1498.90	1513.92	1515.85
1998	11	1627.03	1621.92	1608.34	1617.72	1624.46
2000	12	1721.11	1729.54	1719.16	1717.86	1731.22

PRICES IN DOLLARS PER METRIC TON.

RESULTS FOR THE CASE WITH LOW FOSSIL FEEDSTOCK PRICES

REPORT # 1

PLASTICS PRODUCTION

MATERIAL

AF= SUM GSS= QUANTITY		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	713.92	1483.57	148.29	4860.78	1679.44
1980	2	774.23	1523.19	177.11	4957.12	1732.53
1982	3	828.94	1578.58	205.54	5127.87	1799.33
1984	4	881.70	1644.72	233.53	5351.75	1876.08
1986	5	933.35	1716.50	260.89	5604.54	1958.67
1988	6	984.78	1791.90	287.96	5879.07	2044.50
1990	7	1037.20	1870.88	315.22	6172.44	2134.31
1992	8	1091.54	1953.75	343.24	6483.96	2228.47
1994	9	1148.43	2040.80	372.48	6813.16	2327.70
1996	10	1208.26	2132.20	403.39	7159.80	2432.29
1998	11	1271.51	2228.54	436.47	7523.98	2543.63
2000	12	1337.26	2327.62	471.83	7911.58	2661.80

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 2

PLASTICIZER PRODUCTION

AF= SUM GSS= QUANTITY		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	199.90	287.24	142.08	21.98	39.21	83.96
1980	2	216.79	299.79	139.57	30.91	36.54	90.55
1982	3	232.10	313.38	140.60	38.94	35.87	96.71
1984	4	246.88	327.78	143.86	46.07	36.79	102.75
1986	5	261.34	342.50	148.44	52.44	38.76	108.64
1988	6	275.74	357.34	153.81	58.19	41.66	114.48
1990	7	290.42	372.47	159.81	63.53	45.31	120.39
1992	8	305.63	388.08	166.33	68.65	49.62	126.46
1994	9	321.56	404.29	173.36	73.72	54.55	132.74
1996	10	338.31	421.17	180.84	78.84	60.10	139.29
1998	11	356.02	438.94	188.86	84.15	66.23	146.07
2000	12	374.43	457.05	197.35	89.66	73.02	153.09

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 3

FOOD PACKAGING AND CONTAINERS

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC	 PE PLASTIC	 OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	59.14	61.11	65.05	837.75	481.95
1980	2	66.75	62.63	81.32	863.53	492.42
1982	3	73.14	65.03	95.96	902.60	509.74
1984	4	78.95	68.04	109.15	952.14	531.98
1986	5	84.38	71.42	120.96	1008.17	557.37
1988	6	89.63	75.04	131.64	1069.64	584.85
1990	7	94.84	78.90	141.52	1136.12	614.37
1992	8	100.14	82.99	150.93	1207.57	645.90
1994	9	105.61	87.31	160.11	1283.95	679.53
1996	10	111.28	91.86	169.25	1365.29	715.32
1998	11	117.20	96.66	178.56	1451.62	753.62
2000	12	123.25	101.59	187.89	1544.07	794.37

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 4

MEDICAL SUPPLIES

AF= SUM GSS= QUANTITY		MATERIALS PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC
TIME		1	2	3
1978	1	7.46	9.95	16.59
1980	2	7.38	8.57	21.05
1982	3	7.50	7.81	25.20
1984	4	7.79	7.50	29.24
1986	5	8.24	7.50	33.25
1988	6	8.82	7.74	37.34
1990	7	9.53	8.16	41.61
1992	8	10.37	8.75	46.13
1994	9	11.33	9.47	50.99
1996	10	12.42	10.31	56.25
1998	11	13.64	11.28	61.99
2000	12	14.99	12.38	68.27

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 5

AUTOMOBILE USES

AF= SUM GSS= QUANTITY		MATERIAL		
		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC
TIME		1	2	3
1978	1	65.70	66.65	66.65
1980	2	73.39	68.53	74.73
1982	3	80.95	71.92	84.37
1984	4	88.95	76.69	95.14
1986	5	97.60	82.62	106.69
1988	6	107.08	89.65	118.98
1990	7	117.53	97.74	132.09
1992	8	129.11	106.93	146.17
1994	9	141.92	117.25	161.38
1996	10	156.08	128.75	177.89
1998	11	171.71	141.51	195.92
2000	12	188.95	155.63	215.67

QUANTITIES THOUSANDS OF METRIC TONS.

REPORT # 6

OTHER CONSUMER PRODUCTS

AF= SUM GSS= QUANTITY		MATERIAL			
		PVC WITH DEHP	REGULAR PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4
1978	1	288.88	517.10	827.57	493.46
1980	2	307.04	530.55	877.55	502.03
1982	3	325.94	552.01	934.41	519.04
1984	4	345.79	578.97	997.85	541.85
1986	5	366.20	609.10	1065.34	568.32
1988	6	387.11	641.42	1136.81	597.17
1990	7	408.73	675.73	1212.47	628.27
1992	8	431.27	712.02	1292.70	661.51
1994	9	454.87	750.33	1377.82	697.00
1996	10	479.60	790.69	1468.07	734.79
1998	11	505.61	833.29	1563.69	775.25
2000	12	532.47	877.36	1666.53	818.60

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 7

PLASTICS PRICES

AF= AVERAGE PRICE GSS= PRICES		MATERIAL				
		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	808.32	827.04	886.46	800.85	837.68
1980	2	912.10	931.64	979.12	932.23	995.93
1982	3	920.10	939.57	982.33	939.35	1004.78
1984	4	929.59	949.12	989.38	947.87	1015.31
1986	5	937.59	957.24	996.27	954.99	1024.14
1988	6	947.09	966.92	1005.52	963.51	1034.69
1990	7	956.59	976.63	1015.26	972.04	1045.18
1992	8	966.09	986.36	1025.29	980.58	1055.68
1994	9	975.62	996.13	1035.52	989.14	1066.15
1996	10	985.60	1006.37	1046.29	998.15	1077.07
1998	11	995.17	1016.10	1056.43	1006.86	1087.04
2000	12	1004.51	1025.66	1066.51	1014.72	1096.73

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 8

PLASTICIZER PRICES

AF= AVERAGE PRICE GSS= PRICES		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	791.89	815.59	883.91	884.56	1280.42	940.73
1980	2	994.12	1022.32	1066.33	1111.46	1434.83	1162.21
1982	3	1005.06	1033.50	1076.20	1123.74	1443.17	1174.18
1984	4	1018.17	1046.90	1038.03	1138.45	1453.17	1188.52
1986	5	1029.11	1058.08	1097.91	1150.73	1461.51	1200.49
1988	6	1042.22	1071.49	1109.74	1165.44	1471.51	1214.84
1990	7	1055.34	1084.90	1121.58	1180.16	1481.51	1229.19
1992	8	1068.45	1098.31	1133.42	1194.88	1491.51	1243.54
1994	9	1081.56	1111.72	1145.25	1209.60	1501.51	1257.89
1996	10	1094.77	1125.23	1157.19	1224.43	1511.44	1272.33
1998	11	1102.69	1133.10	1163.12	1232.96	1515.04	1281.39
2000	12	1117.12	1147.91	1176.41	1249.24	1526.63	1297.10

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 13

AVERAGE PLASTICS PRICES

AF= AVERAGE PRICE GSS= PRICES		PLASTICS FOOD USES	MEDICAL SUPPLIES	AUTO USES	CONSUMER PRODUCTS	OTHER DEMAND
TIME		1	2	3	4	5
1978	1	817.70	851.92	840.76	816.77	810.77
1980	2	953.81	954.76	941.40	943.73	940.05
1982	3	961.26	962.57	948.14	951.28	947.68
1984	4	970.31	972.14	957.15	960.43	956.75
1986	5	977.91	980.44	965.07	968.14	964.34
1988	6	987.06	990.42	974.74	977.39	973.38
1990	7	996.22	1000.52	984.54	986.65	982.41
1992	8	1005.39	1010.67	994.40	995.93	991.43
1994	9	1014.58	1020.87	1004.33	1005.23	1000.47
1996	10	1024.23	1031.54	1014.71	1014.99	1009.95
1998	11	1033.37	1041.59	1024.57	1024.27	1019.01
2000	12	1041.92	1051.52	1034.27	1033.05	1027.44

PRICES IN DOLLARS PER METRIC TON.

RESULTS FOR THE CASE WITH HIGH FOSSIL FEEDSTOCK PRICES AND A COMPLETE BAN ON DEHP

REPORT # 1

PLASTICS PRODUCTION

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	0.00	1654.29	188.46	5222.95	1820.30
1980	2	0.00	1652.96	234.02	5194.10	2075.76
1982	3	0.00	1683.64	274.28	5267.33	2252.98
1984	4	0.00	1735.87	311.18	5409.46	2386.34
1986	5	0.00	1800.45	346.01	5586.18	2495.25
1988	6	0.00	1873.21	380.18	5777.53	2596.33
1990	7	0.00	1949.78	414.79	5963.24	2710.22
1992	8	0.00	2025.95	450.62	6132.34	2854.68
1994	9	0.00	2098.23	488.19	6262.85	3054.61
1996	10	0.00	2159.07	527.24	6333.47	3340.42
1998	11	0.00	2200.82	567.10	6325.54	3741.60
2000	12	0.00	2226.97	608.72	6243.52	4258.94

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 2

PLASTICIZER PRODUCTION

AF= SUM GSS= QUANTITY		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	0.00	320.30	155.03	27.94	46.50	93.63
1980	2	0.00	325.25	164.15	40.83	45.06	98.37
1982	3	0.00	332.06	171.36	50.43	47.94	104.14
1984	4	0.00	340.15	177.23	56.69	55.42	110.73
1986	5	0.00	348.42	182.12	59.99	67.40	117.74
1988	6	0.00	356.37	186.58	60.87	83.91	124.96
1990	7	0.00	363.15	191.46	59.77	105.34	132.09
1992	8	0.00	368.12	197.45	57.31	131.66	138.72
1994	9	0.00	370.57	205.54	53.91	163.50	144.51
1996	10	0.00	369.20	216.75	49.90	201.30	148.85
1998	11	0.00	362.94	232.05	45.64	244.93	151.36
2000	12	0.00	352.82	250.16	41.39	295.88	151.87

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 3

FOOD PACKAGING AND CONTAINERS

AF= SUM GSS= QUANTITY		MATERIAL PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC	 PE PLASTIC	 OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	0.00	63.61	67.71	872.02	501.67
1980	2	0.00	62.26	89.71	858.85	554.76
1982	3	0.00	62.84	107.81	869.85	595.31
1984	4	0.00	64.71	123.13	897.58	629.39
1986	5	0.00	67.34	136.42	934.69	660.11
1988	6	0.00	70.46	148.51	976.56	690.56
1990	7	0.00	73.78	159.89	1018.19	725.12
1992	8	0.00	77.02	170.76	1056.38	767.74
1994	9	0.00	79.92	181.16	1085.75	824.21
1996	10	0.00	82.06	190.43	1100.93	901.41
1998	11	0.00	83.02	197.63	1097.65	1005.65
2000	12	0.00	83.00	203.07	1077.59	1136.40

QUANTITIES IN THOUSANDS OF METRIC TONS

REPORT # 4

MEDICAL SUPPLIES

AF= SUM GSS= QUANTITY		MATERIALS PVC WITH DEHP	 REGULAR PVC	 LOW MIG. PVC
TIME		1	2	3
1978	1	0.00	12.75	21.25
1980	2	0.00	10.35	26.58
1982	3	0.00	8.93	31.29
1984	4	0.00	8.16	35.71
1986	5	0.00	7.85	40.00
1988	6	0.00	7.85	44.32
1990	7	0.00	8.07	48.79
1992	8	0.00	8.42	53.52
1994	9	0.00	8.86	58.60
1996	10	0.00	9.37	64.08
1998	11	0.00	9.90	70.01
2000	12	0.00	10.48	76.50

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 5

AUTOMOBILE USES

AF= SUM GSS= QUANTITY		MATERIAL		
		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC
TIME		1	2	3
1978	1	0.00	99.50	99.50
1980	2	0.00	98.33	117.73
1982	3	0.00	100.09	135.18
1984	4	0.00	104.27	152.35
1986	5	0.00	110.32	169.59
1988	6	0.00	117.84	187.36
1990	7	0.00	126.45	206.11
1992	8	0.00	135.92	226.33
1994	9	0.00	146.03	248.43
1996	10	0.00	156.60	272.73
1998	11	0.00	167.55	299.47
2000	12	0.00	179.01	329.15

QUANTITIES THOUSANDS OF METRIC TONS.

REPORT # 6

OTHER CONSUMER PRODUCTS

AF= SUM GSS= QUANTITY		MATERIAL			
		PVC WITH DEHP	REGULAR PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4
1978	1	0.00	598.37	957.63	571.01
1980	2	0.00	594.17	982.10	638.42
1982	3	0.00	605.34	1020.70	689.09
1984	4	0.00	626.80	1069.91	730.65
1986	5	0.00	654.32	1124.51	767.34
1988	6	0.00	685.78	1181.24	803.21
1990	7	0.00	718.98	1235.96	843.95
1992	8	0.00	751.89	1286.35	894.85
1994	9	0.00	782.54	1327.03	963.38
1996	10	0.00	807.32	1352.63	1059.00
1998	11	0.00	822.60	1358.44	1190.85
2000	12	0.00	829.73	1345.45	1359.18

QUANTITIES IN THOUSANDS OF METRIC TONS.

REPORT # 7

PLASTICS PRICES

		MATERIAL				
AF= AVERAGE PRICE GSS= PRICES		PVC WITH DEHP	REGULAR PVC	LOW MIG. PVC	PE PLASTIC	OTHER PLASTICS
TIME		1	2	3	4	5
1978	1	0.00	827.77	887.23	801.82	838.44
1980	2	*********	932.70	980.21	933.55	997.04
1982	3	*********	979.31	1023.12	980.57	1053.76
1984	4	*********	1031.88	1075.03	1033.29	1116.69
1986	5	*********	1089.81	1133.57	1091.69	1184.48
1988	6	*********	1154.06	1198.46	1157.22	1257.43
1990	7	*********	1227.10	1271.21	1232.66	1334.68
1992	8	*********	1306.75	1349.06	1315.23	1411.70
1994	9	*********	1395.65	1434.16	1409.24	1487.42
1996	10	990078.06	1495.52	1528.01	1515.74	1558.20
1998	11	971379.00	1608.03	1632.68	1636.04	1622.68
2000	12	944124.69	1722.77	1737.49	1762.28	1682.31

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 8

PLASTICIZER PRICES

AF= AVERAGE PRICE GSS= PRICES		DEHP	LG.MOL. WT.PAE	SML.MOL. WT.PAE	VL.MOL. WT.PAE	EPOXID. SOY OIL	OTHER PLASTCRS
TIME		1	2	3	4	5	6
1978	1	0.00	815.78	884.75	884.85	1280.82	940.77
1980	2	59581.70	1022.83	1067.50	1112.11	1435.41	1162.51
1982	3	61456.16	1096.60	1132.63	1193.09	1490.43	1241.47
1984	4	63466.27	1179.31	1205.64	1283.87	1552.09	1330.03
1986	5	65547.48	1270.97	1286.54	1384.45	1620.41	1428.20
1988	6	67748.52	1373.81	1377.29	1497.30	1697.04	1538.39
1990	7	70197.37	1492.24	1481.78	1627.26	1785.31	1665.33
1992	8	72590.16	1621.84	1596.13	1769.46	1881.89	1804.27
1994	9	75145.20	1769.26	1726.19	1931.21	1991.75	1962.36
1996	10	77747.75	1934.50	1871.93	2112.45	2114.66	2139.75
1998	11	80801.38	2109.90	2024.87	2305.44	2245.33	2326.03
2000	12	83897.37	2323.33	2214.04	2539.36	2404.40	2556.09

AVERAGE PRICES IN DOLLARS PER METRIC TON.

REPORT # 13

AVERAGE PLASTICS PRICES

		PLASTICS				
AF= AVERAGE PRICE GSS= PRICES		FOOD USES	MEDICAL SUPPLIES	AUTO USES	CONSUMER PRODUCTS	OTHER DEMAND
TIME		1	2	3	4	5
1978	1	818.97	864.93	857.50	818.95	811.82
1980	2	958.70	966.89	958.59	951.63	944.34
1982	3	1009.98	1013.40	1004.49	1002.04	993.87
1984	4	1066.87	1067.01	1057.51	1058.06	1048.92
1986	5	1128.89	1126.39	1116.33	1119.21	1109.23
1988	6	1197.09	1191.78	1181.33	1186.60	1176.04
1990	7	1273.04	1264.95	1254.44	1262.04	1251.55
1992	8	1353.50	1343.32	1333.20	1342.54	1332.85
1994	9	1440.54	1429.11	1419.91	1430.33	1422.89
1996	10	1532.89	1523.87	1516.17	1524.66	1521.46
1998	11	1629.14	1629.63	1623.85	1624.49	1628.08
2000	12	1722.58	1735.72	1732.31	1722.23	1734.62

PRICES IN DOLLARS PER METRIC TON.

RESULTS FOR THE CASE WITH LOW FEEDSTOCK PRICES AND A COMPLETE BAN ON DEHP

```
REPORT # 1

       PLASTICS PRODUCTION

                                            MATERIAL
                          +----------+----------+----------+----------+----------+
AF=  SUM                  | PVC WITH | REGULAR  | LOW MIG. | PE       | OTHER    |
GSS= QUANTITY             | DEHP     | PVC      |  PVC     | PLASTIC  | PLASTICS |
--------------------------+----------+----------+----------+----------+----------+
TIME                      |    1     |    2     |    3     |    4     |    5     |
---------------------+----+----------+----------+----------+----------+----------+
1978                 |  1 |     0.00 |  1654.29 |   188.46 |  5222.95 |  1820.30 |
1980                 |  2 |     0.00 |  1653.10 |   234.03 |  5195.88 |  2075.56 |
1982                 |  3 |     0.00 |  1686.58 |   274.72 |  5289.00 |  2280.75 |
1984                 |  4 |     0.00 |  1742.94 |   312.87 |  5461.68 |  2458.79 |
1986                 |  5 |     0.00 |  1812.59 |   349.60 |  5679.43 |  2619.18 |
1988                 |  6 |     0.00 |  1891.19 |   385.99 |  5928.13 |  2768.40 |
1990                 |  7 |     0.00 |  1977.15 |   423.02 |  6201.43 |  2912.78 |
1992                 |  8 |     0.00 |  2069.83 |   461.53 |  6496.39 |  3056.44 |
1994                 |  9 |     0.00 |  2168.88 |   502.20 |  6811.31 |  3202.33 |
1996                 | 10 |     0.00 |  2274.13 |   545.60 |  7145.15 |  3352.18 |
1998                 | 11 |     0.00 |  2385.91 |   592.35 |  7497.01 |  3508.99 |
2000                 | 12 |     0.00 |  2502.96 |   642.76 |  7871.37 |  3672.15 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

```
REPORT # 2

       PLASTICIZER PRODUCTION

                          +----------+----------+----------+----------+----------+----------+
AF=  SUM                  | DEHP     | LG.MOL.  | SML.MOL. | VL.MOL.  | EPOXID.  | OTHER    |
GSS= QUANTITY             |          | WT.PAE   | WT.PAE   | WT.PAE   | SOY OIL  | PLASTCRS |
--------------------------+----------+----------+----------+----------+----------+----------+
TIME                      |    1     |    2     |    3     |    4     |    5     |    6     |
---------------------+----+----------+----------+----------+----------+----------+----------+
1978                 |  1 |     0.00 |   320.30 |   155.03 |    27.94 |    46.50 |    93.63 |
1980                 |  2 |     0.00 |   325.30 |   164.17 |    40.84 |    45.04 |    98.33 |
1982                 |  3 |     0.00 |   334.74 |   173.55 |    52.03 |    45.07 |   103.43 |
1984                 |  4 |     0.00 |   347.24 |   183.07 |    61.70 |    46.72 |   109.01 |
1986                 |  5 |     0.00 |   361.54 |   192.55 |    70.25 |    49.55 |   114.87 |
1988                 |  6 |     0.00 |   376.99 |   201.94 |    77.98 |    53.49 |   120.99 |
1990                 |  7 |     0.00 |   393.47 |   211.43 |    85.23 |    58.40 |   127.41 |
1992                 |  8 |     0.00 |   410.97 |   221.13 |    92.28 |    64.18 |   134.16 |
1994                 |  9 |     0.00 |   429.48 |   231.16 |    99.36 |    70.79 |   141.28 |
1996                 | 10 |     0.00 |   449.01 |   241.55 |   106.59 |    78.25 |   148.78 |
1998                 | 11 |     0.00 |   469.83 |   252.55 |   114.20 |    86.45 |   156.52 |
2000                 | 12 |     0.00 |   491.42 |   263.98 |   122.13 |    95.61 |   164.72 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

```
REPORT #  3

      FOOD PACKAGING AND CONTAINERS

                                          MATERIAL
                          +---------+---------+---------+---------+---------+
AF=  SUM                  | PVC WITH | REGULAR | LOW MIG. | PE       | OTHER    |
GSS= QUANTITY             | DEHP     | PVC     |  PVC     | PLASTIC  | PLASTICS |
--------------------------+---------+---------+---------+---------+---------+
TIME                      |    1    |    2    |    3    |    4    |    5    |
----------------------+---+---------+---------+---------+---------+---------+
1978                  |  1 |    0.00 |   63.61 |   67.71 |  872.02 |  501.67 |
1980                  |  2 |    0.00 |   62.27 |   89.70 |  859.17 |  554.73 |
1982                  |  3 |    0.00 |   62.88 |  107.49 |  872.66 |  602.05 |
1984                  |  4 |    0.00 |   64.77 |  122.60 |  904.07 |  646.98 |
1986                  |  5 |    0.00 |   67.44 |  135.77 |  946.50 |  690.39 |
1988                  |  6 |    0.00 |   70.64 |  147.63 |  996.95 |  733.08 |
1990                  |  7 |    0.00 |   74.25 |  158.70 | 1053.92 |  776.12 |
1992                  |  8 |    0.00 |   78.21 |  169.37 | 1116.67 |  820.24 |
1994                  |  9 |    0.00 |   82.50 |  179.94 | 1184.78 |  866.02 |
1996                  | 10 |    0.00 |   87.08 |  190.59 | 1258.02 |  913.79 |
1998                  | 11 |    0.00 |   91.96 |  201.54 | 1336.16 |  964.26 |
2000                  | 12 |    0.00 |   97.08 |  212.73 | 1420.12 | 1017.25 |

QUANTITIES IN THOUSANDS OF METRIC TONS
```

```
REPORT #  4

MEDICAL SUPPLIES

                                   MATERIALS
                          +---------+---------+---------+
AF=  SUM                  | PVC WITH | REGULAR | LOW MIG. |
GSS= QUANTITY             | DEHP     | PVC     | PVC      |
--------------------------+---------+---------+---------+
TIME                      |    1    |    2    |    3    |
----------------------+---+---------+---------+---------+
1978                  |  1 |    0.00 |   12.75 |   21.25 |
1980                  |  2 |    0.00 |   10.35 |   26.58 |
1982                  |  3 |    0.00 |    8.98 |   31.45 |
1984                  |  4 |    0.00 |    8.28 |   36.15 |
1986                  |  5 |    0.00 |    8.05 |   40.84 |
1988                  |  6 |    0.00 |    8.14 |   45.65 |
1990                  |  7 |    0.00 |    8.43 |   50.71 |
1992                  |  8 |    0.00 |    9.02 |   56.11 |
1994                  |  9 |    0.00 |    9.72 |   61.94 |
1996                  | 10 |    0.00 |   10.57 |   68.27 |
1998                  | 11 |    0.00 |   11.55 |   75.20 |
2000                  | 12 |    0.00 |   12.67 |   82.79 |

QUANTITIES IN THOUSANDS OF METRIC TONS.
```

REPORT # 5

AUTOMOBILE USES

AF= SUM
GSS= QUANTITY

TIME		MATERIAL PVC WITH DEHP 1	REGULAR PVC 2	LOW MIG. PVC 3
1978	1	0.00	99.50	99.50
1980	2	0.00	98.35	117.75
1982	3	0.00	100.72	135.78
1984	4	0.00	105.80	154.12
1986	5	0.00	112.99	173.00
1988	6	0.00	121.98	192.71
1990	7	0.00	132.65	213.61
1992	8	0.00	144.94	236.05
1994	9	0.00	158.88	260.32
1996	10	0.00	174.50	286.73
1998	11	0.00	191.90	315.61
2000	12	0.00	211.22	347.24

QUANTITIES THOUSANDS OF METRIC TONS.

REPORT # 6

OTHER CONSUMER PRODUCTS

AF= SUM
GSS= QUANTITY

TIME		MATERIAL PVC WITH DEHP 1	REGULAR PVC 2	PE PLASTIC 3	OTHER PLASTICS 4
1978	1	0.00	598.37	957.63	571.01
1980	2	0.00	594.23	982.48	638.38
1982	3	0.00	606.07	1024.59	697.42
1984	4	0.00	628.45	1079.42	752.53
1986	5	0.00	657.18	1142.06	805.12
1988	6	0.00	690.26	1210.88	856.34
1990	7	0.00	726.85	1285.31	907.61
1992	8	0.00	766.56	1365.27	959.89
1994	9	0.00	809.15	1450.79	1013.92
1996	10	0.00	854.51	1541.95	1070.17
1998	11	0.00	902.71	1638.74	1129.53
2000	12	0.00	953.28	1742.58	1191.91

QUANTITIES IN THOUSANDS OF METRIC TONS.

```
REPORT #  7

       PLASTICS PRICES

                                          MATERIAL
                            +---------+---------+---------+---------+---------+
AF=  AVERAGE PRICE          | PVC WITH | REGULAR | LOW MIG. | PE      | OTHER    |
GSS= PRICES                 | DEHP     | PVC     |  PVC     | PLASTIC | PLASTICS |
----------------------------+---------+---------+---------+---------+---------+
TIME                        |    1     |    2    |    3     |    4    |    5     |
-----------------------+----+---------+---------+---------+---------+---------+
1978                   |  1 |     0.00 |  827.04 |   886.46 |  800.85 |   837.68 |
1980                   |  2 |********* |  931.64 |   979.12 |  932.23 |   995.93 |
1982                   |  3 |********* |  939.57 |   982.33 |  939.35 |  1004.78 |
1984                   |  4 |970071.31 |  949.12 |   989.38 |  947.87 |  1015.31 |
1986                   |  5 |886319.94 |  957.24 |   996.27 |  954.99 |  1024.14 |
1988                   |  6 |809119.25 |  966.92 |  1005.52 |  963.51 |  1034.69 |
1990                   |  7 |736331.75 |  976.63 |  1015.26 |  972.04 |  1045.18 |
1992                   |  8 |667935.56 |  986.36 |  1025.29 |  980.58 |  1055.68 |
1994                   |  9 |603926.63 |  996.13 |  1035.52 |  989.14 |  1066.15 |
1996                   | 10 |544300.50 | 1006.37 |  1046.29 |  998.15 |  1077.07 |
1998                   | 11 |491633.72 | 1016.10 |  1056.43 | 1006.86 |  1087.04 |
2000                   | 12 |436369.94 | 1025.66 |  1066.51 | 1014.72 |  1096.73 |

AVERAGE PRICES IN DOLLARS PER METRIC TON.
```

```
REPORT #  8

       PLASTICIZER PRICES

                            +---------+---------+---------+---------+---------+---------
AF=  AVERAGE PRICE          | DEHP     | LG.MOL. | SML.MOL. | VL.MOL. | EPOXID.  | OTHER
GSS= PRICES                 |          | WT.PAE  | WT.PAE   | WT.PAE  | SOY OIL  | PLASTCRS
----------------------------+---------+---------+---------+---------+---------+---------
TIME                        |    1     |    2    |    3     |    4    |    5     |    6
-----------------------+----+---------+---------+---------+---------+---------+---------
1978                   |  1 |     0.00 |  815.59 |   883.91 |  884.56 |  1280.42 |   940.73
1980                   |  2 | 58347.86 | 1022.32 |  1066.33 | 1111.46 |  1434.83 |  1162.21
1982                   |  3 | 56746.71 | 1033.50 |  1076.20 | 1123.74 |  1443.17 |  1174.18
1984                   |  4 | 54766.67 | 1046.90 |  1088.03 | 1138.45 |  1453.17 |  1188.52
1986                   |  5 | 52656.48 | 1058.08 |  1097.91 | 1150.73 |  1461.51 |  1200.49
1988                   |  6 | 50660.21 | 1071.49 |  1109.74 | 1165.44 |  1471.51 |  1214.84
1990                   |  7 | 48655.76 | 1084.90 |  1121.58 | 1180.16 |  1481.51 |  1229.19
1992                   |  8 | 46647.40 | 1098.31 |  1133.42 | 1194.88 |  1491.51 |  1243.54
1994                   |  9 | 44639.51 | 1111.72 |  1145.25 | 1209.60 |  1501.51 |  1257.89
1996                   | 10 | 42634.89 | 1125.23 |  1157.19 | 1224.43 |  1511.44 |  1272.33
1998                   | 11 | 40725.38 | 1133.10 |  1163.12 | 1232.96 |  1515.04 |  1281.39
2000                   | 12 | 38703.60 | 1147.91 |  1176.41 | 1249.24 |  1526.63 |  1297.10

AVERAGE PRICES IN DOLLARS PER METRIC TON.
```

REPORT # 13

AVERAGE PLASTICS PRICES

		PLASTICS				
AF= AVERAGE PRICE GSS= PRICES		FOOD USES	MEDICAL SUPPLIES	AUTO USES	CONSUMER PRODUCTS	OTHER DEMAND
TIME		1	2	3	4	5
1978	1	818.08	864.18	856.75	818.10	810.92
1980	2	957.47	965.81	957.51	950.44	943.10
1982	3	966.12	972.83	964.12	959.02	951.55
1984	4	975.96	981.88	973.00	968.83	961.15
1986	5	984.07	989.85	980.86	976.95	969.06
1988	6	993.62	999.68	990.56	986.49	978.33
1990	7	1003.07	1009.73	1000.47	995.94	987.50
1992	8	1012.47	1019.91	1010.49	1005.35	996.63
1994	9	1021.85	1030.18	1020.60	1014.74	1005.74
1996	10	1031.65	1040.94	1031.19	1024.56	1015.28
1998	11	1040.88	1051.07	1041.19	1033.83	1024.35
2000	12	1049.52	1061.09	1051.07	1042.58	1032.78

PRICES IN DOLLARS PER METRIC TON.